LOWER LEG ANTERIOR AND LATERAL INTRACOMPARTMENTAL PRESSURE CHANGES BEFORE AND AFTER CLASSIC VERSUS SKATE NORDIC ROLLERSKIING IN COLLEGIATE NORDIC SKIERS

by

Katherine Marie Woods

A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Exercise and Sport Science

The University of Utah

December 2011

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

The thesis of **Katherine Marie Woods**

has been approved by the following supervisory committee members:

Charlie Hicks-Little	, Chair	**9/23/2011** Date Approved
Barry B. Shultz	, Member	**9/23/2011** Date Approved
Bradley T. Hayes	, Member	**9/23/2011** Date Approved

and by **Barry B. Shultz**, Chair of

the Department of **Exercise and Sport Science**

and by Charles A. Wight, Dean of The Graduate School.

ABSTRACT

Increasing awareness of chronic exertional compartment syndrome (CECS) among Nordic skiers warrants the need for specific analysis of intracompartmental pressures (ICPs) before and after Nordic skiing. The purpose of this study was to determine if lower leg anterior and lateral ICPs are increased after a 20-minute Nordic rollerskiing time-trial, as well as determine if a difference exists between postexercise ICPs for classic versus skate rollerskiing.

Seven participants were randomly assigned into a technique order group designating which technique, classic or skate rollerskiing, they would perform first. Each technique was performed 7 days apart. Before rollerskiing, preexercise ICP measurements were taken from the anterior and lateral lower leg compartments. Identical methods were used to measure ICPs at the 1st and 5th minute following activity using either the classic or the skate Nordic rollerskiing technique.

Our results showed an increase in ICPs for all participants for the both anterior and lateral compartments (p = 0.000 and p= 0.002, respectively), regardless of technique. A three-way interaction between time, technique, and gender was found for the anterior and lateral compartments and subjective perception of lower leg pain. The males showed statistical significance for the anterior ($t_{(6)} = 8.434$, $p < 0.05$) and lateral ($t_{(6)} = 3.076$, $p < 0.05$) ICPs between baseline and 1-minute postexercise when using the classic technique

versus the skate technique. Although not statistically significant, the females showed higher anterior and lateral ICPs at 1-minute postexercise when using the skate technique versus the classic technique. The males' subjective perception of pain was statistically greater at 1-minute postexercise during classic rollerskiing versus skate rollerskiing, whereas the females' subjective perception of pain was statistically greater at 1-minute postexercise during skate rollerskiing versus classic rollerskiing.

The results of this study suggest that Nordic skiing contributes to increases in ICPs which may lead to the development of CECS. Additonally, there may be a potential gender affect between the Nordic skiing techniques. Further research topic is warranted to better understand the incidence and long-term effects of this phenomenon regarding increased ICPs and symptoms of CECS within the Nordic skiing population.

TABLE OF CONTENTS

Appendix

LIST OF TABLES

CHAPTER I

INTRODUCTION

Background

Chronic Exertional Compartment Syndrome (CECS) is a debilitating condition resulting in loss of function and a decrease in athletic performance. A compartment syndrome occurs when the circulation and function of tissues within a closed space are compromised by increased pressure within that space (Matsen, 1975). Black and Taylor (1993) described CECS as "a reversible, abnormal elevation of tissue pressures within a confined space which compromises local circulation and function and which is brought on by exercise" (p. 408). The authors also stated that an increase in tissue pressure within an enclosed space has the potential to threaten perfusion and tissue viability. CECS most commonly affects individuals who participate in endurance activities, such as runners, soccer players, and military personnel (Padhiar, 2009). Common symptoms of CECS include burning, aching, paresthesia, weakness, and an inability to dorsiflex the foot. These symptoms are detrimental to athletic performance and could even end a career if left untreated. To date, bilateral fasciotomy surgery is the only successful treatment for CECS, costing approximately $5,000.

Recently, anecdotal evidence has shown Nordic skiing to be an additional endurance sport population prone to developing symptoms of CECS. Many Nordic skiers have been diagnosed and treated with surgery in order to return to a previous level of activity within their sport. However, limited research has been conducted with regards to CECS and the Nordic skiing population.

It is unknown whether or not Nordic skiing plays a role in the development of CECS. The purpose of this study was to determine if intracompartmental pressures (ICPs) of both the anterior and the lateral lower leg compartments are increased among collegiate or professional Nordic skiers after a 20-minute Nordic rollerskiing time-trial. The researchers also aimed to determine whether or not a difference exists between post-exercise ICPs when using the classic rollerskiing technique versus using the skate rollerskiing technique.

The researchers hypothesized that ICPs of both the anterior and the lateral lower leg compartments would increase among collegiate or professional Nordic skiers after a 20-minute Nordic rollerskiing time-trial. We believed that postexercise ICPs would be due to contractions of the lower leg muscles during classic and skate rollerskiing rather than the intensity or duration of the Nordic skiing activity itself. During classic rollerskiing the lower leg must produce repetitive concentric dorsiflexion contractions to kick and glide the ski forward. During skate rollerskiing the lower leg must produce repetitive concentric dorsiflexion and eversion contractions to lift the ski off and away from the ground. These movements are followed by eccentric lowering of the foot and concentric inversion at the ankle as the ski returns to the start position on the ground. In order to conclude that any changes in ICPs were not due to intensity, we controlled for variability by measuring blood lactate levels and providing a pre-determined range within which skiers maintained their heart rate during exercise. These measures of intensity were compared from the first week to the second week to note any differences that could be attributed to the Nordic rollerskiing technique used. In addition, the skiers were also instructed to maintain intensity between the levels of 15-17 on the Borg's Rating of Perceived Exertion Scale (Appendix C), which is hard to very hard. Duration was controlled by instructing the participants to stop rollerskiing right at 20 minutes.

The researchers also hypothesized that the skate rollerskiing technique would increase ICPs more than the classic rollerskiing technique for both the anterior and the lateral compartments. This rationale existed because, as previously described, the skate technique involves repetitive eccentric lowering of the ski using the anterior and lateral compartment muscles responsible for dorsiflexion and eversion whereas the classic technique does not. Due to the contraction of tissues while in an elongated state, eccentric contractions may be responsible for greater increases in muscle hypertrophy during exercise.

Significance of Study

This study was important because anecdotal evidence showed that increasing numbers of Nordic skiers are being diagnosed and treated surgically for CECS. However, this condition has yet to be studied within this specific population. This study was the first of its kind regarding CECS and Nordic skiers. At this time, there is no research observing the effects of Nordic rollerskiing on acute ICPs of the lower leg. This study provided objective data showing the effects on the anterior and the lateral compartments of the lower leg after 20 minutes of Nordic rollerskiing using both the classic rollerskiing and the skate rollerskiing techniques. If results are significant, physicians, athletic trainers, coaches, and athletes will better understand this condition with specific regards to the Nordic skiing population. These persons will also have a better idea of how to modify specific training plans for symptomatic athletes as well as ways to prevent occurrence of CECS in an asymptomatic athlete.

Research Questions

The following research questions were addressed in this study:

1. Does Nordic rollerskiing increase ICPs of the anterior and/or the lateral lower leg compartments among collegiate or professional Nordic skiers after a 20-minute time trial activity?
2. Does one technique, skate rollerskiing or classic rollerskiing cause higher ICPs of the anterior and/or lateral lower leg compartments after a 20-minute time trial activity when compared to the other technique?

Hypotheses

The following hypotheses were proposed in this study:

1. Nordic rollerskiing will increase ICPs of the anterior and the lateral lower leg compartments among collegiate or professional Nordic skiers after a 20-minute time trial activity.
2. The skate rollerskiing technique will cause higher ICPs of the anterior and the lateral lower leg compartments after a 20-minute rollerskiing time trial

when compared to the classic rollerskiing technique.

Limitations

The following limitations applied to this study:

1. This study was limited to dry-land Nordic rollerskiing activity and cannot be compared to on-snow Nordic skiing activity.
2. This study was limited to ICPs of the anterior and lateral compartment of the leg and cannot be generalized to the superficial posterior and deep posterior compartments of the leg.
3. This study was limited to professional and collegiate Nordic skiers from the Salt Lake City, Utah area, which limited the ability to generalize the results to a broader Nordic skiing population.
4. This study was limited to skiers who resided in the United States at least 85% of the time during the past 12 months and cannot be generalized to athletes training in other countries.
5. This study was limited to professional or collegiate Nordic skiers w trained at least 500-600 training hours during the past 12 months and cannot be generalized to skiers training below this amount.

Delimitations

The following delimitations applied to this study:

1. All participants were currently registered within the International Ski Federation (FIS).

2. This study recruited skiers from a narrow age range (18-30 years) and a similar Nordic skiing background to provide a homogenous population.
3. This study was limited to skiers with no history of knee, lower leg, or ankle surgery and cannot be generalized to athletes who have had compartment surgery for the treatment of CECS.
4. All participants used the same pair of classic rollerskis during the classic rollerskiing time trial and all participants used the same pair of skate rollerskis during the skate time trial.
5. All participants were instructed to use the same poling technique, V2, during the skate rollerskiing time trial to provide equal pole push to each side during each stride.
6. All participants were instructed to plant poles alternately on the opposite side to the kick during the classic rollerskiing time trial and limit unnecessary double poling as to keep the legs moving.
7. Participants were randomly assigned into a technique order group. This group stated which technique the participant would perform during the time-trial on the first day, either starting with classic rollerskiing or starting with skate rollerskiing.

Assumptions

The following assumptions were the basis of conduct for this study:

1. All participants rollerskied to the best of their ability.
2. All participants arrived rested, without having exercised on the day of the

testing.

3. Some participants may be currently experiencing shin pain but will not have been treated surgically.
4. Some participants may exhibit baseline pressures higher than 15 mmHg during the baseline intracompartmental test period due to the nature of Nordic skiing, and anecdotal evidence of high ICPs within this population. These participants may or may not present with signs or symptoms of CECS. Normal ICPs should range from 0 to 10 mmHg at rest (Anderson, et al., 2006). In addition, in the presence of appropriate clinical findings, a pre-exercise pressure greater than or equal to 15 mmHg is considered diagnostic of CECS (Pedowitz, Hargens, Mubarak, & Gershuni, 1990).

Definition of Terms

Acute Compartment Syndrome (ACS) – A significant clinical problem causing major functional losses following a wide variety of traumatic, vascular, neurological, surgical, pharmacological, renal, and iatrogenic causes. Considered a surgical emergency (Padhiar, 2009).

Chronic Exertional Compartment Syndrome (CECS) – “A reversible, abnormal elevation of tissue pressures within a confined space which compromises local circulation and function and which is brought on by exercise” (Black & Taylor, 1993, p. 408).

Compartment Syndrome (CS) - A condition in which the circulation and function of tissues within a closed space are compromised by increased pressure within that space (Matsen, 1975).

Dominant Leg – Determined by asking the participant which foot he or she would naturally use to kick a ball for distance.

Double Poling – A technique used during classic skiing, when skiers use both poles at the same time to move themselves forward. Correct technique involves reaching ahead with the arms, planting both poles simultaneously, and pulling through with both arms while keeping legs relaxed. It is often used on slightly downhill inclines or on flat terrain (Fortin, 2000, p. 203).

Fasciectomy – A surgical procedure similar to a fasciotomy (see below) with the additional excision of strips of fascial tissue (Padhiar, 2009).

Fasciotomy – A surgical procedure where the fascia around a muscle is cut to relieve tension or pressure within that muscle compartment (Padhiar, 2009).

Intracompartmental Pressure (ICP) – The pressure within a single compartment of the leg, measured in mmHg.

Intracompartmental Pressure Testing – A current gold standard that measures intracompartmental pressures using a needle inserted into each individual muscle compartment (Blackman, 2000; Bong, Polatsch, Jazrawi, & Rokito, 2005; Fredericson & Wun, 2003; Jones & James, 1987; Pell, Khanuja, & Cooley, 2004; Touliopoulos & Hershman, 1997).

Maximum Heart Rate (MHR) – Calculated using the following formula: MHR = 208 - (0.7 x age) (Tanaka, Monahan, & Seals, 2001).

Rating of Perceived Exertion (RPE) – A simple method of rating perceived exertion and can be used by coaches to gauge an athlete’s level of intensity in training and competition (Borg, 1998).

Single bout of rollerskiing activity – For the purposes of this study, a single bout of rollerskiing activity meant that a participant Nordic rollerskied for 20 minutes using either the classic technique or the skate technique. For this study, each participant was instructed to maintain intensity between 15 and 17 on the Borg's RPE and keep his or her heart rate (bpm) between 85%-90% of his or her maximum heart rate for at least 75% percent of the total time-trial (15 minutes).

V2 Poling- A method of poling that employs a double-pole push (pushing poles down on both sides poles) on every leg stride. One of the poling techniques used during the skating technique (Rusko, 2003, p. 50).

CHAPTER II

LITERATURE REVIEW

The purpose of this study was to determine if intracompartmental pressures (ICPs) of both the anterior and the lateral lower leg compartments are increased among collegiate or professional Nordic skiers after a 20-minute Nordic rollerskiing time-trial. The researchers also aimed to determine whether or not a difference exists between postexercise ICPs when using the classic rollerskiing technique versus using the skate rollerskiing technique. ICP testing is an objective tool used to aid in the diagnosis of CECS. Increases in ICPs after an acute bout of Nordic rollerskiing may suggest that this activity leads to the development of CECS. The organization of the topics of this literature review will be as follows: anatomy, compartment syndrome, Nordic skiing, and associated literature.

Anatomy

In order to understand the causes, symptoms, and treatment of CECS, one must have an appreciation for the anatomy of the lower leg. There are four compartments in the lower leg, each containing muscles grouped primarily according to their action. Each group of muscles is individually surrounded by a thick fibrous sheath called the fascia.

The four compartments are classified as anterior, lateral, superficial posterior, and deep posterior. There is controversy over whether or not a “fifth” compartment exists in some individuals, containing only the tibialis posterior muscle. This section describes the individual lower leg muscles and their actions, as well as the neurovascular structures contained within each compartment.

The anterior compartment of the leg consists of the tibialis anterior, the extensor hallicus longus (EHL), the extensor digitorum longus (EDL), and the fibularis (or peroneus) tertius muscles. These four muscles are responsible for dorsiflexion and inversion at the ankle joint. The EHL and EDL are also prime movers during toe extension. The muscles of the anterior compartment play an important role in both techniques of Nordic skiing. In classic skiing, these muscles dorsiflex the ankle to lift the toes during the kick portion of the technique. In skate skiing, these muscles dorsiflex at the ankle to lift the toes and concentrically contract to keep the ski up off the ground. These muscles are also responsible for a eccentric contraction that slowly controls the ski as it returns to the ground. Boundaries of the anterior compartment include the tibia, the interosseous membrane, the fibula, the anterior intermuscular septum, and the deep fascia of the leg. Neurovascularization to the anterior compartment is provided by the anterior tibial artery and vein, and the deep branch of the common fibular (peroneal) nerve (Blackman, 2000; Drake, Vogl, & Mitchell, 2005, pp. 553-555).

The lateral compartment of the leg consists of the fibularis group. This group includes the fibularis longus, and the fibularis brevis muscles. These muscles may also be referred to as peroneals. Together, these two muscles are responsible for eversion and some plantarflexion at the ankle joint. Although the lateral compartment muscles work to stabilize the lower leg during classic skiing, these muscles are primarily activated while using the skate technique. The lateral compartment muscles are responsible for everting the ankle and providing the lateral "push off" observed during skate skiing. Like the anterior compartment, they are also responsible for an eccentric contraction that slowly returns the ski to the start position. Boundaries of the lateral compartment include the anterior intermuscular septum, the fibula, the posterior intermuscular septum, and the deep fascia. Innervation to the lateral compartment is provided by the superficial branch of the fibular nerve (Blackman, 2000; Drake, et al., p. 552).

The superficial posterior compartment consists of the gastrocnemius, the soleus, and the plantaris muscles. The muscles of the superficial posterior compartments are responsible for plantarflexion at the ankle joint and can elevate the body up on to the toes while standing. These muscles aid the Nordic skier during the push off the snow. Because the gastrocnemius and the soleus muscles originate above the knee joint, these two muscles are also responsible for flexion at the knee. The superficial posterior compartment is separated from the deep posterior compartment by a deep transverse fascia. Innervation to the superficial posterior compartment is provided by the sural nerve (Blackman, 2000; Drake, et al., pp. 545-546).

The deep posterior compartment consists of the popliteus, the tibialis posterior, the flexor digitorum longus (FDL), and the flexor hallicus longus (FHL) muscles. The small and superiorly oriented popliteus muscle helps unlock the knee during initial flexion. The FDL muscles are responsible for flexion at the toes, with the FHL muscle primarily responsible for flexion of the great toe. Additionally, these muscles aid in plantarflexion and inversion at the ankle joint. These muscles help stabilize the lower leg during both Nordic skiing techniques and provide balance and proprioception at the ankle joint. Boundaries of the deep posterior compartment include the tibia, the interosseous membrane, the fibula, and the deep transverse fascia. Neurovascularization to the deep posterior compartment is provided by the posterior tibial artery and vein, and the tibial nerve (Blackman, 2000; Drake, et al., pp. 548-549).

More recently, a fifth compartment has been described. This compartment is said to contain only the tibialis posterior muscle, surrounded by a discrete sheath. Some researchers argue that recurrence of symptoms after surgical treatment of the deep posterior compartment may be due to inadequate release of this “fifth compartment” (Davey, Rorabeck & Fowler, 1984; Hislop, Tierney, Murray, O’Brien, & Mahoney, 2003).

Compartment Syndrome

Definition

Compartment Syndrome is defined as a condition in which the circulation and function of tissues within a closed space are compromised by increased pressure within that space (Matsen, 1975). There are two different diagnoses of compartment syndrome: acute compartment syndrome and chronic exertional compartment syndrome. These diagnoses differ in many ways including clinical presentation, treatment, and long-term effects.

Acute Compartment Syndrome

Acute compartment syndrome (ACS) was first described by Dr. Richard Von Volkmann in 1881. Dr. Von Volkmann explained that when dressings are too tight or tourniquets are placed improperly, there is constant constriction to the blood flow within a limb resulting in tissue damage. In essence, he was describing what happens during an acute compartment syndrome (Volkmann, 1881). ACS is characterized by increased pressure within an osteofascial compartment that causes severe pain in the individual. Sustained elevated pressure within the compartment reduces capillary perfusion to levels less than adequate for tissue viability (Pearse, Harry, & Nanchahal, 2002). Decreased capillary perfusion may lead to irreversible muscle, nerve damage, or ultimate loss of limb. ACS is considered a surgical emergency. If not diagnosed and treated quickly, the patient risks loss of muscular function due to permanent neurological changes within the extremity.

ACS is not limited to trauma associated with athletic exercise. The most common causes include fractures, burns, and blunt or crushing injuries that restrict blood flow to an area, snake bites, and postischemic swelling. In these traumatic cases, edema fluid and gross amounts of blood may appear as a result of cell damage and hemorrhage (Mubarak & Hargens, 1981; Pearse, et al., 2002). Vascular, neurological, surgical, pharmacological, renal, and iatrogenic conditions may also be considered, however, the bottom line is to understand that surgery is necessary no matter the cause of ACS (Padhiar, 2009).

Although the pathophysiology and treatment of ACS have been thoroughly described, the condition is rare and not the main focus of the current study. For the remainder of this study, we will focus solely on the less understood form of compartment syndrome, also known as chronic exertional compartment syndrome.

Chronic Exertional Compartment Syndrome

Chronic exertional compartment syndrome (CECS) is defined as “a reversible, abnormal elevation of tissue pressures within a confined space which compromises local circulation and function and which is brought on by exercise” (Black & Taylor, 1993, p. 408). Duggan, MacGill, Reeves, and Goldstein (2009) refer to CECS as an effort induced condition in which tissue pressures within an osteofascial envelope are elevated well above physiological levels. Although surgery is not immediately warranted, CECS considered is a significant clinical problem (Padhiar, 2009).

The first documented case of CECS may have been written as early as 1912 by Dr. Edward Wilson, a medical officer on Scott’s expedition to Antarctica. In his personal journal, Dr. Wilson gave a first account of what was probably an exertion-related anterior compartment syndrome (Freedman, 1953). The first published case of compartment syndrome was written in 1956 by Mavor. The case report was on a young professional football athlete who had been symptomatic for at least 2 years. The athlete was treated with surgery and had successful outcomes (Mavor, 1956).

Pathophysiology

Since Mavor’s report in 1956, much research has been performed in order to better understand the nature of CECS. Still, there is no one concept with which to explain the syndrome’s basic pathophysiology. Instead, there are many theories as to why compartment pressures increase with regard to exercise and patients experience varying degrees of discomfort and pain during activity. The one unifying factor is that all current theories suggest that tissue pressures elevate to levels that result in inadequate muscle perfusion. These elevated pressures seem to be responsible for ischemic-related symptoms, such as pain and loss of function (Detmer, Sharpe, Sufit, & Girdley, 1985; Gebauer, Schultz, & Giangarra, 2005; Leversedge, Casey, Seiler, & Xerogeanes, 2002; Padhiar, 2009).

One theory is that repetitive muscle contractions, as with running for example, cause muscle volume and fluids to increase within a muscle. This increase in muscle volume raises the fascial volume limit, which increases ICPs (Bong, et al., 2005; Starkey & Johnson, 2006). In normal exercising muscle, both the surface area and filling pressure of the capillary increase, which creates an increase in re-absorption. This may result in muscle volume increases by as much as 20% during vigorous exercise (Bong, et al., 2005; Padhiar, 2009). The active muscle does not get adequate perfusion during the contraction phase, but instead gets adequate perfusion during the relaxation phase. If ICPs fail to return to resting levels between contractions or contractions are sustained, perfusion and function can be compromised (Padhiar, 2009).

Another theory is that some individuals possess compartments that are not large enough to handle increases in muscle volume or possess compartments with tight, thickened fascial layers. This supposed loss of elasticity and decreased compliance of the fascia raises ICPs because the fascia is not able to accommodate the increases in muscle volume created during exercise (Bong, et al., 2005; Padhiar, 2009). In a 1985 study, Detmer, et al. reported increased fascial thickening in 25 of 36 samples. However, it is not known whether or not these increased fascial thickenings were the cause or the result of chronically increased compartment pressures (Pedowitz & Gershuni, 1995).

A third theory is that normal muscles achieve hypertrophy over time with chronic exercise. This may also reduce the volume available within a fascial compartment (Bong, et al., 2005). Pedowitz and Gershuni (1995) agree that exercise induced muscle hypertrophy, combined with excessive training, may predispose an individual to the development of CECS.

It is obvious that further studies are needed to understand the pathophysiology of CECS. With a unified concept describing the etiology of this syndrome, we will begin to understand how to avoid CECS development and how to manage pain, which seems due to ischemia resulting from increased pressures.

Clinical Presentation

It is difficult to determine the presence CECS relying on a physical exam alone. However, there are some hallmark symptoms of CECS that are commonly described. The main characteristic of CECS is that it involves exercise induced pain that is relieved with cessation of activity (Blackman, 2000; Bong, et al., 2005; Padhiar, 2009). Although symptoms usually develop within 20 to 30 minutes after the onset of exercise, the amount of exercise required to bring on pain varies greatly between individuals (Bong, et al., 2005; Starkey & Johnson, 2006). However, this amount of exercise is usually constant for each individual, meaning that the pain occurs at the same interval or intensity during subsequent training sessions (Blackman, 2000; Bong, et al., 2005; Edwards & Myerson, 1996; Touliopoulos & Hershman, 1997; Wilder & Sethi, 2004).

Most symptomatic individuals describe the pain as cramping, burning, tenderness, and/or tightness in the affected leg (Anderson, Parr, & Hall, 2006; Bong, et al., 2005; Edwards, Wright, & Hartman, 2005; Moeyersoons & Martens, 1992; Prentice, 2006;

Starkey & Johnson, 2006). Symptoms of CECS are bilateral in up to 80%-95% of patients (Detmer, et al., 1985; Mohler, Styf, Pedowitz, Hargens, & Gershuni, 1997). Some individuals will experience a sensation of increased fullness, tension, or girth in the involved compartments and a nonlocalized palpable tenderness is frequently observed after exercise (Blackman, 2000; Edwards et al., 2005, Fraipont & Adamson, 2003). In cases of severe CECS, muscle weakness and paresthesia may be elicited to light touch (Pell et al., 2004). Pain is not usually present at rest and is rarely provoked by walking, except in severe cases where it may actually occur at rest (Padhiar, 2009). The pain of CECS usually forces the individual to stop any exercise activity.

In their 1985 study, 87% of the patients of Detmer, et al. were involved in some sport activity. Most individuals diagnosed with CECS are involved in repetitive athletic activities, such as running, soccer, or football (Bong, et al., 2005). However, these individuals can be involved in non-running sports as well and participate at either the recreational or the professional level (Detmer, et al., 1985). Others have reported symptoms of CECS that occur after increases in activity, training and/or intensity, changes in training surface or footwear, or a combination of the above. Biomechanical factors have also been deemed culprits of the syndrome. The exact etiology of CECS and the reasons some individuals are more susceptible than others continues to remain unknown, but a pattern is emerging as more individual cases are reported (Padhiar, 2009).

Some researchers have stated that males are more likely to be diagnosed with CECS (Cohen, 2002; Martens & Moeyersoon, 1990; Styf, 1988) whereas others say that the syndrome is equally distributed between the genders (Blackman, 2000; Detmer, et al., 1985; Gerow, Matthews, Jahn, & Gerow, 1993; Pedowitz, et al., 1990; Touliopoulos, et al., 1997). This may be due to the fact that women continue to increase their involvement in sport. Although CECS appears to be more common in the younger population (Stein & Sennett, 2005), it can occur up to any age. In 1995, Amendola and Webster-Bogaert correlated clinical features with pressure measurements. They calculated that the most important criteria for CECS were as follows: (a) the individual is less than 30 years old, (b) the pain is reproduced with exercise, (c) there is no tenderness upon palpation, (d) the symptoms are bilateral, and (e) the activity profile matches one with repetitive-type exercise, such as running. Regardless of their sport activity, almost all individuals diagnosed with CECS agree that pain adversely affects their athletic performance (Bong, et al., 2005).

Incidence

In a study of patients with undiagnosed lower leg pain, the incidence was 14% (Qvarfordt, Christenson, Eklöf, Ohlin, & Saltin, 1983). In a study of patients with symptoms of anterior lower leg pain provoked by chronic exercise, the incidence was 27% (Styf, 1988). Certain studies have reported large groups of patients with CECS, such as Reneman (1975) with 61 patients, Detmer, et al. (1985) with 100 patients, and Allen and Barnes (1986) with 100 patients.

Ninety-five percent of all cases of CECS occur in the lower leg (Howard, Mohtadi, & Wiley, 2000). Among these lower leg cases, diagnosis of the anterior and deep posterior compartments are most common, involving 40% to 60% of patients and 32% to 60% of patients, respectively. The lateral compartment is involved in 12%-35% of patients and the superficial posterior compartment is involved in 2%-20% of patients

(Detmer, et al., 1985; Martens, Backaert, Vermaut, & Mulier, 1984; Pedowitz, et al., 1990). Other authors cite the anterior compartment as the most common for diagnosis, followed by the lateral, then deep, and superficial posterior (Bourne & Rorabeck, 1989; Verleisdonk, Schmitz, & van der Werken, 2004).

Differential Diagnosis

Differential diagnosis for CECS includes medial tibial stress syndrome (MTSS), tibial and fibular stress fractures, and deep vein thrombosis (Mazzerole, McDermott, & Silverberg, 2008). In addition to these conditions, Bong, et al. (2005) also cite fascial defects, nerve entrapment syndromes, vascular claudication, and lumbar disc herniation as possible differential diagnoses. Pedowitz and Gershuni (1995) add periositis, tendinitis, excessive pronation, venous stasis, and neurogenic claudication to this list. Although rare, CNS or primary muscle disorders, infections, or tumors have also been cited as differential diagnoses for CECS (Mubarak, 1989; Styf, 1989).

CECS is commonly misdiagnosed and referred to using the catch-all term “shin splints.” On the other hand, some patients undergo bilateral fasciotomy surgeries only to have their symptoms return because their condition was misdiagnosed as CECS. Therefore, it is important to take the whole picture into account, gathering a thorough subjective and objective physical examination as well as ICP measurements.

Diagnosis

Currently, the most valuable tool used to confirm CECS in a patient is the recording of intracompartmental tissue pressures (Blackman, 2000; Bong, et al., 2005;

Fredericson & Hun, 2003; Jones & James 1987; Pell, et al., 2004; Touliopoulos & Hershman, 1997). Although there is neither universal agreement as to the best technique nor consensus as to what pressure levels are required for diagnosis, it is clear that pressure measurements should be made before and after exercise. In addition, the exercise should closely mimic the physical activity that normally provokes symptoms in the patient (Bong, et al., 2005; Martens & Moeyersoons 1990).

Edwards, et al. (2005) recommended that pressures should only be measured before and after exercise because measurements during exercise often are difficult to obtain and as a result are unreliable (Blackman, 2000; Edwards & Myerson, 1996; Pedowitz, et al., 1990; Rorabeck, Bourne, Fowler, Finlay, & Nott, 1988). ICPs within a normal compartment should range from 0 mmHg to 10 mmHg (Anderson, et al., 2006). Postexercise ICP measurements should be recorded the 1st and 5th minute after activity (Pedowitz, et al., 1990) and in the absence of CECS, ICPs should return to preexercise levels within 3 to 5 minutes after cessation of activity (Jones & James, 1987).

In 1990, Pedowitz, et al. developed criteria for diagnosing CECS that is convenient and easy to perform in the outpatient office setting. As described by the aforementioned authors: “In the presence of appropriate clinical findings, we consider one or more of the following intramuscular pressure criteria to be diagnostic of chronic compartment syndrome of the leg: (a) a preexercise pressure greater than or equal to 15 mmHg, (b) a 1-minute postexercise pressure of greater than or equal to 30 mmHg, and/or (c) a 5-minute postexercise pressure greater than or equal to 20 mmHg” (Pedowitz, et al., 1990, p. 40). Some authors maintain that preexercise pressure measurements greater than 15 mmHg or a long period before pressures return to normal is vital in confirming CECS

(Rorabeck, et al., 1988).

Still, it is important to remember that positive pressure tests are insufficient to make a CECS diagnosis on their own. The gold standard method of ICP testing will never replace a thorough history or examination. Although elevated pressures may exist after exercise, the patients must be symptomatic of CECS to be diagnosed with CECS (Amendola & Rorabeck, 1985; Rorabeck, et al., 1988). The hallmark of CECS will always be pain induced by exercise (Pedowitz & Gershuni, 1995).

Treatment

Initially, nonsurgical treatment is proposed for managing symptoms of CECS. Methods of nonsurgical treatment include the following: rest, stretching, strengthening, ice or heat application, physiotherapy, acupuncture, steroids, foot orthotics, osteopathy, deep massage, trigger point therapy, and homeopathy. Initiatives to address extrinsic factors such as modifications to training surface, shoe design, and training intensity or frequency may be warranted. In addition, biomechanical abnormalities, muscle imbalances, flexibility, and limb alignment may also be addressed (Edwards, et al., 2005). Cycling can be substituted as a method of maintaining cardio-respiratory fitness for those in whom pain is provoked by running (Beckham, Grana, Buckley, Brezaile, & Claypool, 1993). Regardless of these treatment attempts, research shows that nonsurgical treatments may have short-term effects but no long-term successful outcomes (Padhiar, 2009). Nonsteroidal anti-inflammatory medications (NSAIDs) are also ineffective (Turnipseed, Detmer, & Girdley, 1989). The only truly successful method of nonsurgical treatment is to completely give up the activity that is causing the pain. Obviously, this is not an option for most professional, or even recreational athletes (Bong, et al., 2005; Padhiar, 2009).

Surgical treatment is recommended if symptoms persist longer than 3 months and non-surgical treatment methods have failed (Edwards, et al., 2005). A fasciotomy is a surgical procedure where the fascia around a muscle is cut length-wise to relieve tension or pressure within that muscle compartment (Padhiar, 2009). The main goal of the procedure is to increase the volume in a compartment to allow for increases in muscle volume during exercise (Padhiar, 2009). Success rates are usually good following a fasciotomy, but rates do vary between individual surgeons and the affected muscular compartment. A patient may have up to four compartments released at once; however, it is customary to release only the compartment that presents with elevated pressures and is symptomatic. Anterior compartment releases are usually more successful than posterior compartment releases (Abramowitz & Schepsis, 1994). A fasciectomy is a similar surgery and is sometimes performed when fasciotomy has failed. This procedure involves removing a ribbon of fascia and is usually performed as an open procedure and requires a longer incision (Padhiar, 2009). Risk factors for surgery are the same as any invasive procedure and include neuropraxia, infection, dehiscence, hematoma, deep vein thrombosis (DVT), and venous damage (Padhiar, 2009). Care must also be taken to avoid damaging the superficial fibular nerve as it passes between the anterior and lateral compartments.

Rehabilitation/Return to Activity

After fasciotomy surgery, early active and passive range of motion (ROM) and partial weight-bearing are encouraged to help prevent post operative fascial scarring

(Blackman 2000; Edwards & Myerson, 1996; Fraipont & Adamson, 2003, Wilder & Sethi, 2004). Table 1 illustrates the common rehabilitative approach for a patient's full return to activity after fasciotomy surgery. Obviously, these are guidelines and times for activity may overlap among different individuals.

Nordic Skiing

Background

The origin of Nordic skiing, also known as cross-country skiing, dates back to at least the third millennium B.C. Originally developed as a means of transportation over icy and snowy surfaces, Nordic skiing is probably the oldest sport to still maintain popularity throughout the world today. The overall goal of competitive Nordic skiing is to ski a set distance in the fastest time. Nordic skiing competitions started in Norway in the late 18th century and many races were held in the 19th century as well. However, it was not until 1900 that Nordic skiing was recognized as a sports event. Today, the International Ski Federation (FIS) continues to regulate the sport and has done so since 1924. Nordic skiing became an Olympic sport for men in 1924 and was added for the

Table 1. Timeline for Return to Activity Following Surgical Fasciotomy

Activity	Time Post Surgery
Weight-bearing as tolerated	1-2 weeks
Stationary bicycle	2 weeks
Isokinetic strengthening	3-4 weeks
Running	5-6 weeks
Speed and agility	8 weeks
Return to full sport activity	8 -12 weeks

(Blackman, 2000; Edwards & Myerson, 1996; Fraipont & Adamson, 2003.

women in 1952 (Fortin, 2000, p. 202).

Nordic skiing requires extreme endurance and muscular power. Skiers have many dry-land methods of training during the summer including, running, cycling, rollerskiing, and glacier skiing. The successful Nordic skier possesses strong and well developed technical skills. He or she is also prepared psychologically, as these elite athletes are often required to perform under extreme exertion and variable conditions.

There are two styles of Nordic skiing, the classic technique and the skate technique. The classic technique uses a traditional diagonal stride with double poling on trails over a groomed track. Average speeds among the best classic skiers can be greater than 25 km/hr. The skate technique is also known as freestyle. This technique was introduced in the Olympics for the first time in Calgary in 1988. Average speed among the best skate skiers can reach 30 km/hr (Fortin, 2000, pp. 202-203).

Classic Nordic Skiing

The basic motion of the classic technique is diagonal and can be broken up into three different phases: the push (or kick) phase, the glide phase, and the end of movement. Sometimes this is referred to as “kick-and-glide.” The push phase starts with a quick extension of the skier’s leg to push off, followed by the hip. The body leans forward and the ankle of the supporting leg is flexed. The opposite arm and leg are outstretched fully. During the glide phase, the shoulder and arm are extended forward to plant the pole on the opposite side from the propelling leg. The body should form a straight line at the end of the push while transferring weight to the supporting ski as the other foot moves forward. The end of movement is signaled when the arms and poles return to the starting position.

Double poling is a method of poling used for slight hills and flats. It is performed by actively pushing down and through on the poles to propel the body forward without using the lower extremity. In normal diagonal motion, the poles are planted alternately on the opposite side of the push, or kicking leg (Fortin, 2000, p. 203).

Skate Nordic Skiing

Skate Nordic skiing technique involves a decisive weight transfer onto one ski angled and then the other, supported by the inner edge of the ski on the snow. Sliding one leg forward, the skier pushes off on the other leg, which is placed at an angle to obtain a better push-off. The motion looks similar to an ice skater. The slower the skier is going, the more propulsion is gained from the upper body. There are different limb-movement patterns used for different terrains and speeds. V2 is a method of poling in which the skier will push both poles into the snow during each leg push-off, creating a symmetrical pole plant to either side (Rusko, 2003, p. 50).

Nordic Ski Equipment

Nordic skis are light and solid, often crafted out of woven carbon fibers with a honeycomb structure. The skis are always taller than the skier and are based on skier weight to provide adequate instep strength. Nordic skis usually do not have metal edges.

For classic technique, it is important that the skis be rigid. They are usually wider and longer than skate skis so that they can distribute the skier’s weight more evenly. Skis are also cambered to create the “kicking zone”. A limited side-cut and a straighter profile help the ski to track and glide forward easily. Classic skis may be wax-less (also known as fish scales) or require wax. Skate skis are generally narrower than a classic ski with minimal side-cut to increase stability in the glide phase. Some have a wider nose to enhance the skating movement and tips are generally less curved than classic skis. When snow conditions are harder-packed, a shorter ski is used. Skate skis require wax.

Nordic ski bindings hold the boot to the ski. In Nordic skiing, only the front of the boot is attached to the ski. Certain bindings are only compatible with certain styles of boots. The bindings must be set so the skier's weight is on the point of the ski that ensures the best contact with the snow. Nordic boots are much lighter than alpine skiing boots, are not rigid, and do not come high up the leg. Classic boots are flexible and provide increased ankle mobility similar to a running shoe. Skate boots are usually higher, stiffer, and reinforced around the heel and ankle. They provide good lateral control and ankle support, beneficial during the push-off.

Lastly, Nordic ski poles are made of graphite and Kevlar® specifically designed to be rigid and light. They are longer than poles used for alpine skiing and should be sized proportionally to the height of the skier. Generally, poles are longer when using the skate technique (Fortin, 2000, p. 203).

Nordic Rollerskiing

Rollerskiing is a typical dry-land method of Nordic ski training and may be performed using either the classic or the skate technique. Shortened Nordic skis with one wheel at each end can be used over smooth indoor or outdoor surfaces. The skiing action is very similar to actual Nordic skiing on snow.

Classic rollerskiing uses the same ‘kick and glide’ motion as on snow. Classic rollerskis usually have wider wheels and a ratchet mechanism on one of the wheels that only rolls forward, providing resistance on the “kick,” comparable to grip wax on snow. Skate rollerskiing uses the same lateral leg push as on snow. Skate rollerskis usually have narrower wheels, similar to in-line skates. Both wheels roll freely. Boots and bindings are the same as those used for skiing on the snow for both techniques. The same poles are used as on the snow; however, the tip may be changed depending on training surface.

Associated Literature on CECS

There have been multiple case studies describing CECS among the athletic population. However, research is limited with regards to the Nordic skiing population. Beckham, et al. (1993) and Baltopoulos, Papadakou, Tsironi, Karagounis, and Prionas (2008) both present research studies on endurance-sport athletes. In 1993, postexercise anterior compartment pressures were compared in asymptomatic competitive runners and cyclists (Beckham, et al., 1993). The authors found no statistical significance in the preexercise pressures; however, the postexercise pressures were significantly higher in runners after maximal exercise ($p = 0.016$). In 2008, anterior compartment pressures were compared between asymptomatic long distance runners (5000 m) and recreational athletes (Baltopoulos, et al., 2008). The results of this study confirmed the correlation between long distance running and increased risk for the development of CECS. To our knowledge, there have only been two research articles published on Nordic skiing and CECS. Gertsch, Borgeat, and Wälli (1987) failed to support their hypothesis that Nordic skate skiing contributed to a case presentation of CECS. In 1992, Lawson, Reid, and

Wiley compared the effect of using skate or classic skis on anterior compartment pressures during Nordic skate skiing activity. The study showed no statistically significant change in pressures when using classic or skate skis while practicing the skate technique. In 2010, a case study written on anterior compartment syndrome in a collegiate male Nordic skier was presented at the National Athletic Trainer's Association (NATA) annual meeting (Woods, Nakagama, Yochem, & Hicks-Little, 2010). The case study presented a symptomatic male skier with a preexercise ICP of 42 mmHg and a postexercise ICP of 81 mmHg for the anterior compartment. The skier was diagnosed with CECS and was successfully treated with bilateral anterior and lateral compartment fasciotomies. The current study aims to fill a gap in the literature by providing a research study regarding CECS and the Nordic skiing population.

CHAPTER III

METHODS

Selection of Participants

Eight volunteers were recruited for the study. Seven healthy individuals participated in the study (3 men, 4 women; age = 22.71 ± 1.38 yrs, height = 175.36 ± 6.33 cm, mass = 71.71 ± 6.58 kg). One participant dropped out before any involvement in the study due to illness. All participants were collegiate Nordic skiers averaging 500-600 training hours per year and registered with the International Ski Federation (FIS). All participants trained using both the classic Nordic skiing technique and skate Nordic skiing technique for at least the past 12 months and were also familiar with rollerskiing as a dry-land method of training. Due to anecdotal evidence that a greater percent of Nordic skiers from the United States are diagnosed with CECS, all participants met the inclusion criteria stating that they had trained in the United States for at least 85% of the time over the past 12 months. All participants were healthy with no history of knee, lower leg, or ankle surgery.

Instrumentation

Pregnancy Test

Because Nordic skiing is a strenuous activity and might potentially cause harm to a fetus, the First Response ® Early Result pregnancy test was used to determine if any female participant should be excluded from the study. In a research study conducted by Cole, Khanlian, Sutton, Davies, and Rayburn (2004), The First Response ® Early Result pregnancy test consistently detected 12.5mIU/mL of human chorionic gonadotropin (hCG) in urine, which is the sensitivity needed to detected 95% of pregnancies at the time of missed menses.

Intracompartmental Pressures

A Stryker Quic STIC Intra-Compartmental Pressure Monitoring System (model no. 295, Stryker Surgical, Kalamazoo, MI) was used to obtain all ICP measurements for the anterior and lateral compartments. This model uses an 18-gauge needle with side-port and digital readout in millimeters of mercury (mmHg). According to a study by Moed and Thorderson (1993) no significant differences were found between the side-ported needle and the slit catheter for the measurement of compartment pressures (p = 0.355, 1-β = 0.90). The slit catheter is considered a gold standard in compartment pressure testing (Rorabeck, Castle, Hardie, & Logan, 1981). Moed and Thorderson (1993) also showed the over-all intraclass correlation was 0.96 ($p < 0.001$) between these slit catheter and the side-ported needle. The absence of a difference and the high intraclass correlation suggests very good agreement between the methods. In addition, the side-ported needle can test multiple compartments at a time which makes it a more cost effective option for use in the acute setting (Moed & Thorderson, 1993).

Blood Lactate

A Lactate Plus portable hand-held blood lactate analyzer was used with Microlet® lancets to obtain participant blood lactates in mmol/L. Correlations for repeat measurements of the same blood sample by the same Lactate Plus analyzer was r = 0.990. Correlations for repeated measurements of the same blood sample using two Lactate Plus analyzers was r = 0.999. Correlations for repeated measurements of the same blood sample using the Lactate Pro versus Lactate Plus was r = 0.990 (Tanner, Fuller, & Ross, 2010). Blood lactates were used as a quality control measure to determine if the participant was exercising at the same intensity level from the first rollerskiing trial to the second rollerskiing trial regardless of technique used.

Heart Rate

A Polar © FT 80 Heart Rate Monitor was worn by each participant during testing. This heart rate monitor uses a chest strap and wrist watch. Heart rates in beats per minute (bpm) were recorded during the entire 20-minute time-trial to determine if athletes performed the activity at the desired intensity. Before exercise, participants were instructed on this desired intensity range with which to keep their heart rate in during the time-trial. This range was set between 80% and 95% of their MHR, which was calculated using the formula: MHR = 208 – (0.7 x age) (Tanaka, et al., 2001). Individual participant heart rates were compared between the first trial and the second trial to determine whether the skiers performed the activities at a comparable intensity regardless of technique used.

Rollerskiing Equipment

To eliminate any differences between skis during testing, one pair of classic and one pair of skate skis were used for all testing sessions. One pair of Marwe 700 Classic rollerskis (Finn Sisu, Finland) were used for all classic rollerski activity. These classic skis were mounted with Rottafella Classic NNN R3 Racing bindings (Rottafella, Norway). One pair of Marwe 610 C Skate Nordic rollerskis (Finn Sisu, Finland) were used for all skate rollerski activity. These skate skis were mounted with Rottafella Skate NNN R3 Bindings (Rottafella, Norway). Without bindings, the classic and skate rollerskis weighed 1.95 kg a pair and 1.75 kg a pair, respectively. Each pair of bindings weighed 0.27 kg a pair. To maintain a comfortable and familiar testing environment, participants wore their own classic and skate boots and used their own classic and skate poles. Four of the participants wore Alpina (Alpina, Slovenia) brand classic and skate boots during testing. Three of the participants wore Rossignol (Rossignol, France) brand classic and skate boots during testing.

Seven-Day Physical Activity Recall (PAR)

The Seven-Day PAR (Appendix B) was used to estimate the participant's time spent in physical activity, strength, and flexibility activities for the 7 days prior to each trial (Sallis, Haskell, & Wood, 1985). This interview was conducted as a quality control measure to determine if the participant's activities leading up to each trial were similar enough to eliminate the prior week's activity as a possible confounding variable. Each interview was conducted and recorded by the same interviewer for each participant before the first trial and before the second trial.

Borg’s Rating of Perceived Exertion (RPE)

The Borg’s RPE 6-20 point scale (Appendix C) was used to explain the intensity at which participants were expected to rollerski (Borg, 1998). Before exercise, each athlete was shown the scale and was instructed to exercise at an intensity between 15 and 17, which are hard and very hard on the Borg’s RPE. The Borg’s RPE was used as a quality control measure to help the athletes maintain the same level of intensity between the first trial and the second trial.

Numerical Rating Scale (NRS)

The eleven-point NRS (Appendix D) was used to objectively determine if the participant was experiencing any lower leg pain or discomfort. The participants were instructed not include any physical pain or discomfort specifically caused by any needle insertion procedures in this response.These values were collected and recorded before exercise, at 1-minute postexercise, and at 5-minutes postexercise. According to the NRS the responses are equivalent to pain ratings as follows: 0 = none, 1 to 3 = mild, 4 to 6 = moderate, and 7 to 10 = severe.

Procedures

Participant Instruction and Permissions

After approval from the IRB, athletes from the University of Utah Nordic Ski Team were invited to attend an informational meeting in which the process of the study was explained. Nordic coaches associated with the United States Skiing and Snowboarding Association (USSA) were also contacted with recruitment information to pass on to any interested Nordic athletes. During the informational meeting, athletes were told that participation in the study was voluntary and the opportunity for drop out was available for any reason during any point in the study. Questions regarding the study were answered and consent forms were signed, which signified an agreement to take part in the study. After signing the consent form, the participants were required to fill out a Pre Participation Health Questionnaire (PPHQ) and answer questions about their experience with Nordic skiing and any leg pain (Appendix A). Participants were randomly assigned to a technique order group which designated the technique, either classic or skate rollerskiing, that the participant would use during the first trial. Next, each participant was scheduled for an afternoon time slot spaced 30 minutes apart to attend for each week's trial. Athletes were instructed to arrive to each trial well rested, without having performed any exercise on the test day.

Protocol

All testing was conducted by two board certified orthopedic physicians and the primary investigator at Sugar House Park in Salt Lake City, UT. The course for the 20-minute time-trial was a paved loop with lanes specifically created for joggers and cyclists and separate from motorized vehicle traffic. This area is commonly used as a rollerski training location for the University of Utah Nordic Ski Team. The paved loop was approximately 2.21 km and had a total elevation gain of 26 m and a total elevation change of 51 m. The overall temperature for the first trial was approximately 50°F and the paved surface was dry. During the second trial, the temperature was approximately 40°F with intermittent periods of wind, hail, and light rain. The paved surface was dry for some participants and slightly wet for others.

According to the methods of Baltopoulos, et al. (2008), trials were performed 7 days apart to avoid any residual effects. Each participant arrived at the course 15 minutes prior to their scheduled time slot to allow adequate time for set-up, baseline testing, and the Seven-Day PAR Interview (Appendix B). In addition, each female was required to take a First Response ® Early Result pregnancy test to determine if she should be excluded from the study. Upon arrival, each participant put on the Polar © FT 80 Heart Rate Monitor, a safety vest, and appropriate boots to be used for that day's trial, classic or skate.

For compartment testing, the participant laid back on a treatment table in the dependent position with his or her boots on. Because it is common for CECS to occur bilaterally, it is custom to only take ICP measurements of the more symptomatic or dominant leg. Therefore, anterior and lateral ICP measurements were taken from the dominant leg, or the symptomatic leg if applicable. The participant's knee was hung in a dependent position off the table and the ankle joint was relaxed. The participant was instructed to lie still and not pull back away from the needle to avoid compression to the posterior compartments that may affect the ICP measurement. After injection of lidocaine for numbing purposes, ICPs were obtained using the Stryker Quic STIC hand-held monitior (model no. 295, Styker Surgical, Kalamazoo, MI). Anterior intracompartmental pressures were obtained from the muscle belly over the mid-shaft of the tibia. Lateral ICPs were obtained from the lateral compartment, between the lateral malleolus and fibular head. ICP measurements were obtained by the same two board certified orthopedic physicians during all testing sessions. All injection sites were wiped with sterile gauze and covered with a Band-aid® and Powerflex™ to be worn loosely during the 20-minute time-trial.

At the same time, a lancet was used to prick the finger and the Lactate Plus Blood Analyzer was used to analyze the participant's blood lactate levels. The participant was also instructed to rate any leg pain they were experiencing at this time, not related to the actual ICP testing, on the eleven-point NRS (Appendix D).

Just before starting to exercise, each participant was read a script describing the trial (Appendix E; Appendix F). The script instructed the participants to rollerski for 20 minutes while keeping their heart rate between 85% to 90% of their MHR, using the formula: MHR = 208 – (0.7 x age) (Tanaka, et al., 2001). This heart rate range was given to each participant to note on the heart rate monitor during activity. Participants were also shown the Borg's RPE Scale (Appendix C) and instructed to exercise at a level of 15 to 17, which is between hard and very hard, or very strenuous (Borg, 1998). When using the classic rollerskiing technique, participants were instructed to double pole as little as possible to maintain continuous lower leg movement. When using the skate rollerskiing technique, participants were instructed to use the V2 method of poling to maintain even poling to both sides. The importance of skiing for only 20 minutes was expressed to the participant and he or she was instructed to wait on the side of the course for assistance in the event of any complication during testing.

Postexercise methods for obtaining measurements were identical to the preexercise methods. Anterior and lateral compartment ICPs, blood lactate levels, and lower leg pain were each obtained at 1-minute postexercise and at 5-minutes postexercise. Table 2 describes the time-line for data collection. All data were recorded at baseline, 1-minute postexercise, and 5-minutes postexercise.

Table 2. Timeline for Data Collection

Orientation	Introduction, Consent Form, PPHQ
Day 1	Meet participant, conduct pregnancy test (females), skier puts on HR monitor, a vest, and appropriate boots and poles, and completes 7-day PAR interview
0 minutes	Obtain preexercise anterior and lateral ICPs, blood lactate, and leg pain measures
21 minutes	Obtain 1-minute postexercise anterior and lateral ICPs, blood lactate, and leg pain measures
25 minutes	Obtain 5-minute postexercise anterior and lateral ICPs, blood lactate, and leg pain measures
Day 2	Meet participant, conduct pregnancy test (females), skier puts on HR monitor, a vest, and appropriate boots and poles, and completes 7-day PAR interview
0 minutes	Obtain preexercise anterior and lateral ICPs, blood lactate, and leg pain measures
21 minutes	Obtain 1-minute postexercise anterior and lateral ICPs, blood lactate, and leg pain measures
25 minutes	Obtain 5-minute postexercise anterior and lateral ICPs, blood lactate, and leg pain measures

Research Design and Statistical Analysis

Appropriate data screening techniques were used to determine if there were missing values or outliers. The normality of anterior and lateral ICPs and lower leg pain ratings were checked. Mauchley's Test for Sphericity was used to check for circularity and compound symmetry. Blood lactates, heart rates, and Seven Day PAR interviews were checked to make sure there were no confounding variables that would affect the results.

The data was analyzed using a 2x2x3 mixed factorial repeated measures design . The independent variables were Nordic ski technique (classic and skate), gender (male or female), and time (preexercise, 1-minute postexercise, and 5-minutes postexercise). The dependent variables were anterior and lateral compartment ICPs (mmHg), and also lower leg pain, according to subjective participant data gathered using the eleven-point NRS.

CHAPTER IV

RESULTS AND DISCUSSION

Demographic Information

Participant demographics are illustrated below in Table 3. The study consisted of seven collegiate Nordic skiers (4 females, 3 males). The average age of participants was 22.71 ± 1.38 years old. Initially, 8 individuals were recruited, one of which dropped out due to illness before the start of the study. All data discussed in this paper represent the 7 participants who completed the entire study. Participants were from three countries; 5 participants were American, 1 was Canadian, and 1 was from Sweden. One participant had undergone previous ICP testing and had been diagnosed with CECS, but not treated with surgery. All participants described themselves as asymptomatic for lower leg pain at the beginning of the study.

Table 3. Participant Demographics

Demographic	N	Mean	SD
Age (years)	7	22.710	1.38
Height (cm)	7	175.36	6.33
Weight (kg)	7	70.71	6.58
Resting Heart Rate (bpm)	7	51.83	9.08
Maximum Heart Rate (bpm)	7	192.07	0.84
Years Skiing	7	10.57	2.94

Results

Intracompartmental Pressure

Anterior Compartment

The ANOVA results for the anterior compartment indicated a significant three-way interaction ($F_{(2,10)} = 13.23$, $p = 0.002$). An additional data analysis using a Helmert contrast revealed statistical significance for the technique x time x sex interaction between the preexercise measure and both postexercise measures ($p = 0.010$, $F_{(1,5)} = 16.633$). A moderator approach to the significant interaction effect using a single degree of freedom contrast (Jaccard, 1998) revealed that males showed a statistically significant ($t_{(6)} = 8.434$, $p < 0.05$) increase in postexercise anterior intracompartmental pressures after using the classic rollerskiing technique compared to the skate rollerskiing technique at 1 minute but there was no significant decrease at 5 minutes for either the classic or skate technique, whereas females showed a similar increase in postexercise anterior intracompartmental pressures after using the classic or the skate rollerskiing techniques at 1 minute recovery but a nonsignificant similar decrease in pressure at 5 minutes for both the classic and skate technique (Table 4 and Figure 1). The individual data are contained in Table 5.

Lateral Compartment

The 2x2x3 ANOVA three-way interaction for lateral compartment pressure (see Table 6 and Figure 2) revealed a statistically significant interaction effect ($F_{(2,10)} = 7.74$, $p = 0.009$). An additional data analysis using a Helmert contrast revealed that the baseline values were statistically lower than the average of both recovery pressure values ($F_{(1,5)} =$

Table 4. ANOVA Table for Anterior Intracompartmental Pressures

Source	**SS**	**Df**	**MS**	**F**	**Sig.**	**η^2**	**1-β**
Between-Subject							
Sex	151.11	1	151.11	3.48	0.121	0.410	0.329
Error (Sex)	217.20	5	43.44				
Total	368.32	6	194.56	3.48	0.121	0.410	0.329
Within-Subject							
Technique	869.53	1	869.53	14.71	0.012	0.746	0.861
Technique * Sex	1327.63	1	1327.63	22.46	0.005	0.818	0.962
Error (Technique)	295.61	5	59.12				
Time	1514.91	2	757.45	22.01	0.000	0.815	0.999
Time * Sex	104.05	2	52.03	1.51	0.267	0.232	0.249
Error (Time)	344.14	10	34.41				
Technique * Time	336.46	2	168.23	9.62	0.005	0.658	0.927
Technique * Time * Sex	462.93	2	231.47	13.23	0.002	0.726	0.981
Error (Technique * Time)	174.97	10	17.50				
Total	5430.23	35	3517.37	83.53	0.291	3.995	4.979

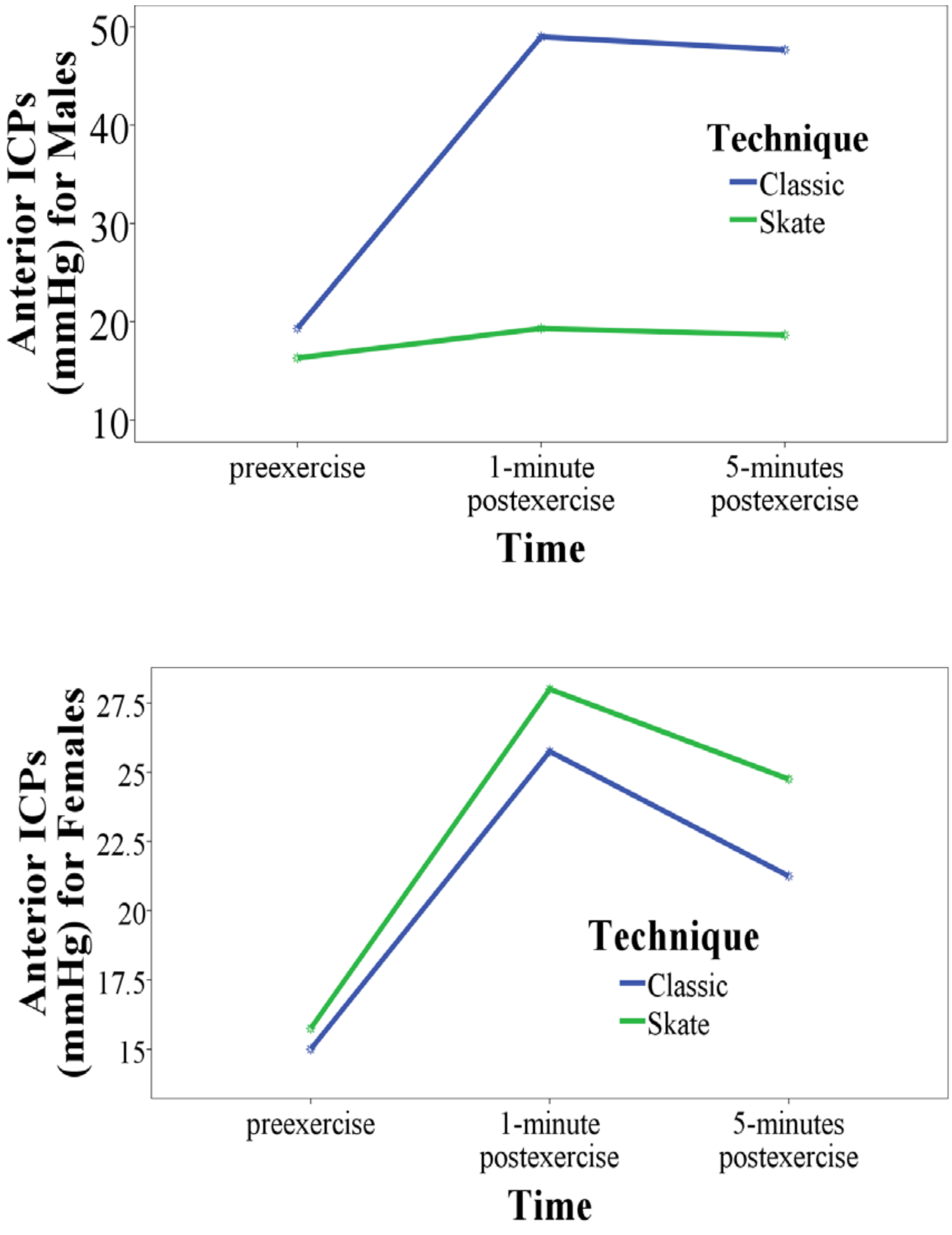


Figure 1. Three-way interaction of gender, technique, and time on anterior compartment pressures.

Table 5. Anterior Intracompartmental Pressures (mmHg) for Classic vs. Skate Technique

			Classic Technique			Skate Technique		
ID	Sex	Technique 1st Trial	Preexercise	1-minute Postexercise	5-minutes Postexercise	Preexercise	1-minute Postexercise	5-minutes Postexercise
1	M	Classic	18*	58*	58*	18*	19	16
2	M	Classic	14	42*	39*	18*	24	24*
3	F	Skate	15*	20	18	14	22	18
4	F	Skate	20*	32*	28*	19*	44*	34*
5	F	Skate	8	31*	26*	13	27	30*
6	F	Classic	17*	20	13	17*	19	17
7	M	Classic	26*	47*	46*	13	15	16

Note: * indicates a pressure that meets diagnostic criteria set forth by Pedowitz, Hargens and Mubarak (1990).

38.045, $p = 0.002$). A single degree of freedom contrast for the males indicated that lateral pressure increased more in the classic technique than skate technique from baseline to 1 minute of recovery ($t_{(6)} = 3.076$, $p < 0.05$) and the skate technique showed a greater decrease in lateral pressure than the classic technique from 1 minute of recovery to 5 minutes of recovery. For females, there was a similar increase in both classic and skate technique from baseline to 1 minute of recovery, however, the females showed a greater reduction in lateral pressure for the classic technique from 1 minute of recovery to 5 minutes of recovery compared to the skate technique. The individual lateral pressure values are presented in Table 7.

Table 6. ANOVA Table for Lateral Intracompartmental Pressures

Source	SS	df	MS	F	Sig.	η^2	1-β
Between-Subject							
Sex	176.10	1	176.10	7.55	0.040	0.601	0.599
Error (Sex)	116.67	5	23.33				
Total	292.76	6	199.43	7.55	0.040	0.601	0.599
Within-Subject							
Technique	11.46	1	11.46	0.51	0.506	0.093	0.091
Technique * Sex	43.46	1	43.46	1.94	0.222	0.280	0.207
Error (Technique)	111.78	5	22.36				
Time	651.89	2	325.95	13.35	0.002	0.727	0.981
Time * Sex	21.32	2	10.66	0.44	0.658	0.080	0.103
Error (Time)	244.25	10	24.43				
Technique * Time	19.41	2	9.70	1.07	0.379	0.176	0.187
Technique * Time * Sex	140.27	2	70.13	7.74	0.009	0.607	0.861
Error (Technique * Time)	90.64	10	9.06				
Total	1334.48	35	527.21	25.05	1.776	1.963	2.430

Lower Leg Pain

The 2x2x3 ANOVA for perception of lower leg pain (see Table 8 and Figure 3) also revealed a statistically significant three-way interaction ($F_{(2,10)} = 9.453$, $p = 0.005$). An additional analysis using a Helmert contrast again indicated that the baseline pain values were statistically lower than the recovery values combined. The single degree of freedom post hoc comparison for males indicated that perceptions of pain increased greatly from the baseline to 1 minute recovery for the classic technique but not for the skate technique. There was no change in pain perceptions across the two techniques from 1 minute of recovery to 5 minutes of recovery. The single degree of freedom contrast for females indicated a statistically significant increase in subjective pain perception for the

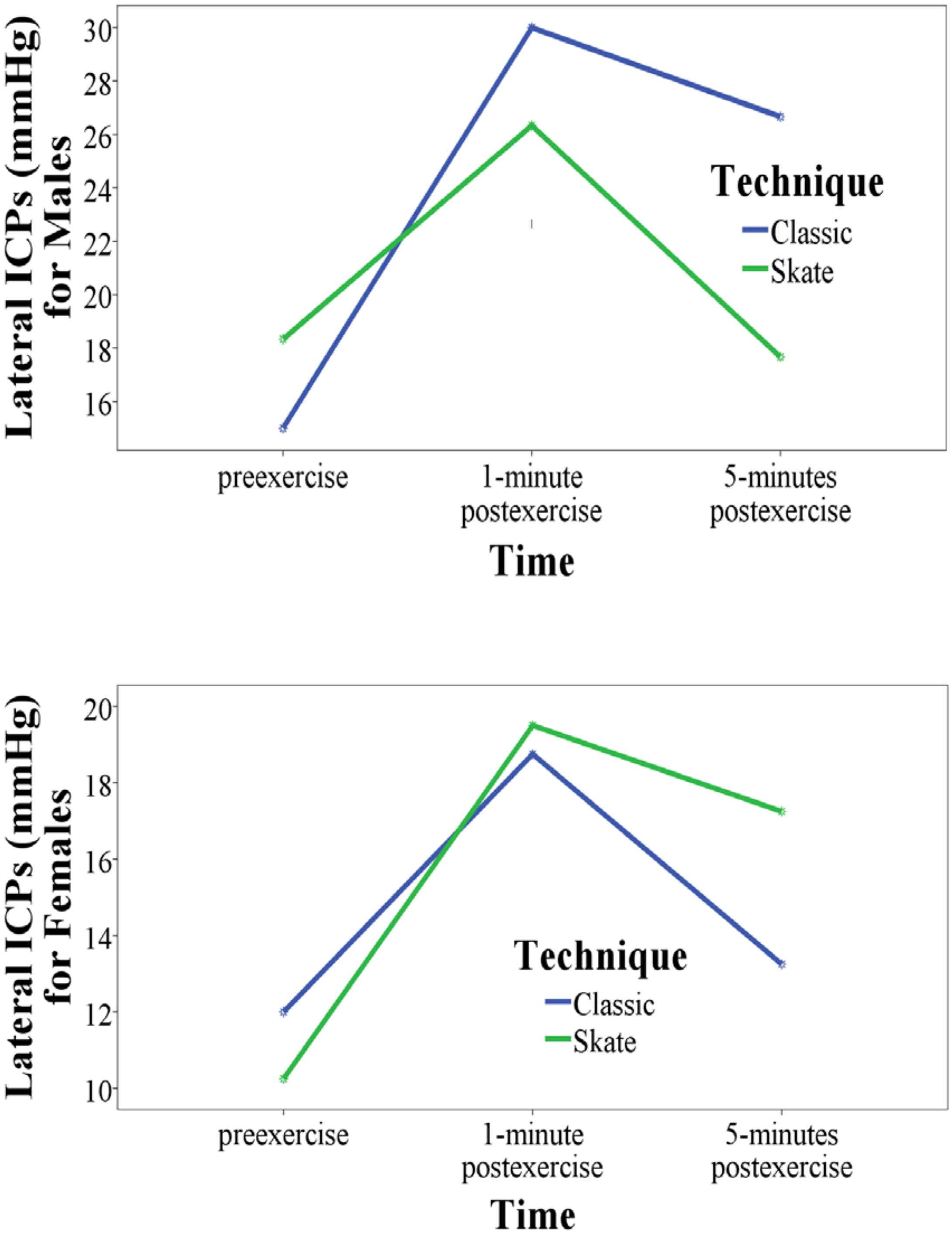


Figure 2. Three-way interaction of gender, technique, and time on lateral compartment pressures.

Table 7. Lateral Intracompartmental Pressures (mmHg) for Classic vs. Skate Technique

			Classic Technique			Skate Technique		
ID	Sex	Technique 1st Trial	Preexercise	1-minute Postexercise	5-minutes Postexercise	Preexercise	1-minute Postexercise	5-minutes Postexercise
1	M	Classic	12	22	21*	23*	29	10
2	M	Classic	17*	40*	32*	18*	30*	28*
3	F	Skate	13	13	10	13	20	17
4	F	Skate	16*	24	16	11	23	19
5	F	Skate	8	24	18	6	20	19
6	F	Classic	11	14	9	11	15	14
7	M	Classic	16*	28	27*	14	20	15

Note. *indicates a pressure that meets diagnostic criteria set forth by Pedowitz, Hargens, and Mubarak (1990).

skate technique compared to the classic technique and although there was a slight decrease for both techniques from 1 minute of recovery to 5 minutes of recovery, the decrease in pain perception was not statistically significant. The individual pain ratings are contained in Table 9.

Participant intensity, measured using average heart rate (bpm) and blood lactate levels (mmol/L) was the same regardless of technique used. There was no statistically significant technique interaction for average heart rate (p = 0.896). A statistically significant increase in blood lactate levels was expected and was observed across time (p = 0.000). However, there was no statistically significant time x technique x sex interaction for blood lactate levels (p = 0.257)

Table 8. ANOVA for Lower Leg Pain

Source	SS	Df	MS	F	Sig.	η^2	1-β
Between-Subject							
Sex	0.677	1	0.677	0.410	0.550	0.070	0.082
Error (Sex)	8.259	5	1.652				
Total	8.936	6	2.33	0.41	0.550	0.070	0.082
Within-Subject							
Technique	0.008	1	0.008	0.004	0.955	0.001	0.050
Technique * Sex	22.294	1	22.294	9.884	0.026	0.664	0.711
Error (Technique)	11.278	5	2.256				
Time	10.004	2	5.002	4.629	0.038	0.481	0.642
Time * Sex	0.956	2	0.478	0.443	0.654	0.081	0.103
Error (Time)	10.806	10	1.081				
Technique * Time	0.052	2	0.026	0.068	0.935	0.013	0.058
Technique * Time * Sex	7.194	2	3.597	9.453	0.005	0.654	0.922
Error (Technique * Time)	3.806	10	0.381				
Total	66.398	35	35.12	24.48	2.613	1.894	2.486

Discussion

The purpose of this study was to determine if ICPs of both the anterior and the lateral lower leg compartments are increased among collegiate or professional Nordic skiers after a 20-minute Nordic rollerskiing time-trial. The results confirmed our hypothesis that Nordic rollerskiing increases ICPs of the anterior and lateral lower leg compartments among collegiate or professional Nordic skiers after a 20-minute time-trial activity. These results were collaborated by an increase in pain perception from a baseline assessment until a 1-minute and 5-minute recovery assessment. These results support the findings of Baltopoulos, et al. (2008) in their study comparing anterior intracompartmental

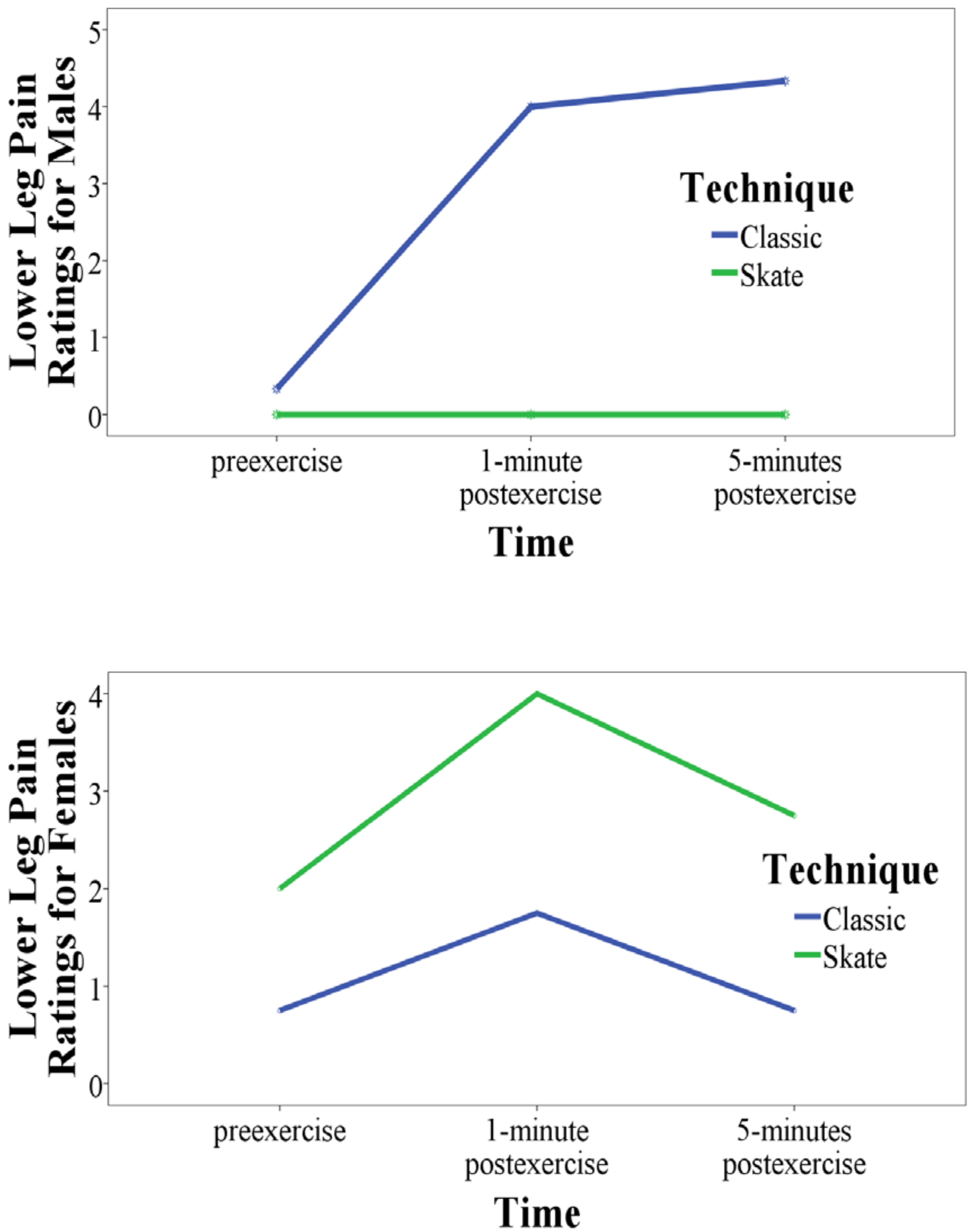


Figure 3. Three-way interaction of gender, technique, and time on lower leg pain ratings using the eleven-point NRS.

Table 9. Lower Leg Pain for Classic vs. Skate According to the Eleven-Point Numerical Rating Scale

			Classic Technique			Skate Technique		
ID	Sex	Technique 1st Trial	Preexercise	1-minute Postexercise	5-minutes Postexercise	Preexercise	1-minute Postexercise	5-minutes Postexercise
1	M	Classic	0	7	6	0	0	0
2	M	Classic	1	5	5	0	0	0
3	F	Skate	0	0	0	0	0	0
4	F	Skate	1	7	7	3	0	0
5	F	Skate	0	4	2	0	2	0
6	F	Classic	0	5	3	1	7	5
7	M	Classic	0	2	1	0	0	0

pressures between male and female recreational athletes and long distance runners. Baltopoulos, et al. (2008) found results confirming the correlation between long distance runners and the increased risk of CECS, demonstrated by postexercise pressure increases within the anterior compartment after an acute bout of treadmill exercise. However, in this 2008 study, no participant complained of symptoms of lower leg pain or discomfort during activity (Baltopoulos, et al., 2008). In addition, the mean value of the baseline anterior ICPs for the male athletes in the Baltopoulos study were 6.78 mmHg lower than the mean value of the baseline anterior ICPs for the male Nordic skiers in the current study. Similarly, the mean value of the baseline anterior ICPs for the female athletes in the Baltopoulos study were 6.81 mmHg lower than the mean value of the baseline anterior ICPs for the female Nordic skiers in the current study. According to these findings, further research may be warranted to determine if a different set of protocols should be used to diagnose CECS in Nordic skiers and if the Pedowitz criterion is valid to use in similar cases involving elite or professional endurance athletes.

The current study was also concerned with whether or not a difference exists between postexercise ICPs when using the classic rollerskiing technique versus using the skate rollerskiing technique. It was hypothesized that the skate rollerskiing technique would cause higher ICPs of the anterior and lateral lower leg compartments after a 20-minute rollerskiing time-trial. Previous research (Pedowitz, et al., 1990) has suggested that 5 minutes after exercise, ICP should begin to return toward baseline values compared to 1 minute after exercise. The results partially agreed with the hypothesis with regard to a statistically significant difference between the techniques for postexercise ICPs for both the anterior and lateral compartments. The results were complicated somewhat by a statistically significant three-way interaction between gender, technique, and time. The females showed higher anterior and lateral compartment pressures with the skate technique although they were not statistically greater at 1 minute of recovery compared to the classic technique. The female's subjective perception of pain with the skate technique, however, was statistically greater than their pain perception with the classic technique. The males, however, showed statistically greater anterior and lateral compartment pressures and subjective pain perception with the classic technqiue compared to the skate technique at 1 minute of recovery. Figures 1 and 2 describe total anterior and lateral ICP changes over time for the classic versus skate rollerskiing technique. To our knowledge, this is the only study comparing changes in anterior and lateral intracompartmental pressures for classic versus skate Nordic rollerskiing.

Although there are no additonal studies comparing the anterior and lateral intracompartmental pressures of male and female Nordic skiers after exercise, the 2008 study by Baltopoulos, et al. did detect a significant difference between male and female recreational athletes (control group) and male and female endurance runners (athlete group) at 1 minute before exercise and at 1 minute after starting exercise. At the 1st minute into exercise, the control male group showed higher intracompartmental pressure than the control women group, whereas the athlete men group showed higher intracompartmental pressure than the athlete women group. No significance was found at 5 minutes after exercise, and no data were collected at 1 minute after exercise. The current study supports that gender may cause differences in lower leg intracompartmental pressures. However, we lack current research demonstrating postexercise differences in intracompartmental pressures related to gender with which to compare our results.

Our results demonstrated that the classic rollerskiing technique increased both the anterior and lateral postexercise ICPs more than the skate rollerskiing technique in the male participants, but boththe classic andthe skate rollerskiing technique produced similar increases in anterior and lateral 1-minute postexercise ICPs among the female participants (Tables 4 and 6). Differences in the anterior and lateral ICPs were noted between the preexercise measures and the combination of the 1-minute and 5-minute postexercise pressures by the Helmert contrasts. More research is needed to determine why males and females show different postexercise results following classic versus skate rollerskiing activity.

Although no hypothesis was stated concerning ICP from 1 minute of recovery to 5 minutes of recovery, researchers have suggested that the pressures should begin to decrease and this has been used clinically as a diagnostic indicator of CECS. The results from this study showed that the males showed very little recovery in anterior compartment pressure when using either technique, whereas the females showed additional recovery regardless of the technique or whether anterior or lateral compartment pressures were measured. The males did show the beginnings of additional recovery regardless of technique in the lateral compartment.

Lower leg pain was not considered a dependent variable in this study, because all participants stated they were asymptomatic before the start of the study. However, because increased ICPs and lower leg pain seem to be related, we wanted to examine the relationship between the two. Our results demonstrated that the classic rollerskiing technique increased lower leg pain more than the skate rollerskiing technique in the male participants when comparing the preexercise measurements to both the 1-minute and the 5-minute postexercise measurements (Tables 8 and 9) whereas the females responded with higher perception of pain after using the skate technique. Using the subjective pain responses given by the participants before and after activity, however, it appears that males complained of greater symptoms of lower leg pain during classic rollerskiing, whereas females perceived more pain in the skate technique. Figure 3 describes the changes in total lower leg pain over time for the classic versus skate rollerskiing technique. It is interesting to note that these results seem to correlate with the results for increased anterior ICPs for the males during classic rollerskiing, whereas the female classic pain scores seemed less correlated with both anterior and lateral ICPs. Although statistical significance is observed, it is also important to remember that the lower leg pain measurements were obtained using the NRS, which is a scale based on subjective participant response. The results suggest a gender difference but futher research is needed.

CECS has been described among runners, cyclists, and military personnel (Padhiar, 2009). However, no research study has been aimed at studying the effects of Nordic skiing on increases in ICPs. Anecdotally, some athletes complain of more pain during classic rollerskiing than during classic snow skiing, which could be attributed to the weight of the ski (2.5 kg per pair compared to approximately 1.18 kg per pair). Newer anecdotal evidence has suggested that increased pressure observed during the classic rollerskiing technique may be attributed to the quality of the rollerski wheels and the effort needed by the skier to maintain forward tracking and control of his or her own ski while in motion. This suggestion parallels with similar anecdotal reports of increased lower leg pain while skate skiing in icy conditions, where one must sustain muscular contractions in the lower leg and foot to maintain control of the ski.

ICP measurements for asymptomatic compartments should stay below 15 mmHg at rest (Pedowitz, et al., 1990) Objective criterion for the diagnosis of CECS has been established by Pedowitz, et al. (1990) and is widely used in the clinical setting as well as in various compartment pressure studies. The criterion states that when combined with a thorough history and clinical exam, diagnosis may be achieved if the patient meets one or more of the following three requirements: (a) a resting pressure of 15 mmHg or more; (b) a 1-minute postexercise pressure greater than or equal to 30 mmHg; and/or (c) a 5-minute postexercise pressure greater than or equal to 20 mmHg. According to these diagnostic criteria, all seven participants in this study would have been diagnosed with CECS for the anterior compartment (Table 5) and four of the seven participants in this study would have been diagnosed with CECS for the lateral compartment (Table 7).

In the assumptions, we stated that due to the repetitive nature of Nordic skiing as an endurance sport, some participants may exhibit ICPs greater than 15 mmHg for their preexercise measurement. For the anterior compartment, 6 participants presented with ICPs greater than 15 mmHg at rest for one or both of the trials. For the lateral compartment, 4 participants presented with ICPs greater than 15 mmHg at rest for one or both of the trials. It is possible that either the diagnostic criterion is not adequate to be used with Nordic skiing, or Nordic skiing plays a role in the development of high ICPs. One should note that these measurements were taken after a 20-minute time-trial. Most Nordic skiers will exercise for at least a minimum of 60 minutes during a single workout. Equally important is remembering that this study was performed on asymptomatic, collegiate Nordic skiers between the ages of 18-30 years. In order for a diagnosis to be made, the patient must also have a clinical presentation that is indicative of CECS.

Limitations

Although we were still able to detect statistical significance, the biggest limitation of this study was a small sample size. Due to time, health issues, and availability of eligible recruits, we were unable to establish a larger sample. This study recruited both professional and collegiate Nordic skiers, however, only Division I collegiate level skiers were able to participate. Second, the majority of the data for the study was collected outdoors. The change in environmental conditions may have had an adverse effect on the participant's ability to ski, the temperature of their muscles, and perception and attitude of the skier. Third, more than one board certified orthopedic physician was responsible for obtaining the ICP measurements which may have affected intertester reliability.

Finally, although the order of testing was determined by random assignment, all of the males (3) did the classic technique first. This potential confounding of order and gender has the potential to bias the gender outcomes. The absence of any order effect being influenced by the weather was at least partially eliminated by the absence of any differences in intensity from week 1 to week 2. Nevertheless, the small sample size and potential confounding of order and gender should temper conclusions drawn from this research. Additional research aimed at replicating this study is needed.

CHAPTER 5

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE RESEARCH

Summary

The first purpose of this study was to determine if ICPs of the anterior and the lateral lower leg compartments are increased after a 20-minute Nordic rollerskiing time-trial. The second purpose of this study was to determine whether or not a difference exists between postexercise ICPs when using the classic versus skate rollerskiing technique. This study was performed using intracompartmental pressure testing to compare anterior and lateral baseline and postexercise ICPs at the 1st and 5th minute following classic and skate Nordic rollerskiing on two different days.

Findings

The results of this study showed three 3-way interactions between time, technique, and gender for the anterior compartment, the lateral compartment, and perceptions of lower leg pain. The males showed statistical significance for the anterior and lateral ICPs between baseline and 1-minute postexercise when using the classic technique versus the skate technique. Although not statistically significant, the females showed higher anterior and lateral ICPs at 1-minute postexercise when using the skate technique versus the classic technique. The males' subjective perception of pain was statistically greater at 1-minute postexercise during classic skiing versus skate skiing, whereas the females' subjective perception of pain was statistically greater at 1-minute postexercise during the skate technique versus the classic technique.

Conclusions

This study presented and discussed Nordic skiing and CECS. It was determined that postexercise anterior and lateral ICPs are significantly increased compared to preexercise anterior and lateral ICPs following both the classic and skate rollerskiing techniques. There also appears to be a gender factor with regard to technique and increased ICPs, with only the male participants showing significantly higher increases in postexercise anterior and lateral ICPs following classic skiing versus skate skiing. The results of this study suggest that Nordic skiing contributes to increases in ICPs, which may lead to the development of CECS. Additional research on this topic is warranted to better understand its incidence and long-term effects within this specific population.

Recommendations for Future Research

As the first study of its kind on Nordic skiing and CECS, there are many opportunities for future research on this topic. This study could be repeated with a larger sample size in order to increase its power and better detect statistical significance. It would be interesting to study the preexercise and postexercise ICPs among skiers previously treated by surgical fasciotomy, rather than just asymptomatic skiers with no history of treatment for CECS. This study was confined to dry-land rollerskiing activity. It would be interesting to see how anterior and lateral ICPs compare with regard to Nordic skiing on the snow. Additional studies involving fine wire electromyography (EMG) to understand the contract-relaxation phase of certain muscles during classic and skate skiing would also be beneficial. This new knowledge would help to better the present phenomenon in which Nordic athletes commonly experience increase in the anterior and lateral compartments during ski activity, particularly during classic rollerskiing and skate skiing over icy snow.

APPENDIX A

PREPARTICIPATION HEALTH QUESTIONNAIRE

Last Name* First Name* Nationality*

***All identifying information will be coded and remain confidential.**

Height (cm)	Weight (kg)	Age (yr)	Blood Pressure	HR at rest (bpm)	Maximum HR (bpm)	Gender (M/F)	Dominant Leg (L/R)

Please answer the following questions about your current health.
Briefly explain "YES" answers below each question.

1. Has a doctor ever denied or restricted your participation in sports? **YES** **NO**

2. Are you currently under treatment for an illness? **YES** **NO**

3. Are you currently taking medication? If yes, please list. **YES** **NO**

4. Have any close members of your family (parents, uncles, aunts, siblings) under 50 years of age died suddenly of a heart problem? **YES** **NO**

5. Have you been hospitalized during the **<u>past 12 months</u>**? **YES** **NO**

6. Do you have asthma? (if you have an inhaler, please bring it to testing) **YES** **NO**

7. Do you have diabetes? **YES** **NO**

8. Have been told you had a heart problem or heart disease? **YES** **NO**

9. Have you passed out or nearly passed out with exercise? **YES** **NO**

10. Have you experienced **severe** pain in your chest during exercise? **YES** **NO**

11. Have you had Mono within the past 6 weeks? **YES** **NO**

12. Have you had a serious head injury or concussion? **YES** **NO**

13. Do you have a seizure disorder? **YES** **NO**

14. Have you had any surgery in the **<u>past 12 months</u>?** **YES** **NO**
   a. Type of surgery:
   b. Date of surgery:

15. Have you had any injuries in the **<u>past 12 months</u>?** **YES** **NO**
   a. Type of injury:
   b. Date of injury:

16. Is there any other problem or concern that we should be aware of? **YES** **NO**

Please answer the following questions regarding your Nordic level of experience/training and leg pain, if applicable.

1. How many years have you been competitively Nordic skiing? ________
2. How many hours per week do you put into training? _______ Per year? ________
3. Please rate the following off-snow methods of training you use. You may repeat a number. (1- main method, 2-3 used very often, 4-5 used fairly often, 6-7-used least often, 0-never used)

    1. Classic roller ski ________
    2. Skate roller ski ________
    3. Running ________
    4. Ski-walking/hill bounding ________
    5. Weight-lifting ________
    6. Ski Erg (or equivalent) ________
    7. Cross-training (swim, bike, elliptical, hiking, kayaking, ect.) ________

4. Have you ever had to take time off because of lower leg pain that started and increased during a specific activity, but decreased with rest? **YES NO**
   How long: __________________ (please note mins, hours, days, months or years)
5. Where did you most often experience this pain? (Rate: 1 (most often) to 3 (least often), 0-never)
   front of the leg ________
   side of the leg ________
   back of the leg ________
6. Have you ever undergone intracompartmental pressure testing? **YES NO**
7. Have you ever been diagnosed with Chronic Exertional Compartment Syndrome (CECS)? **YES NO**

I certify that I have answered the above questions truthfully and to the best of my knowledge and fully understand that approval for participation in this study is based in large part upon the above information.

____ __________________
Participant Signature Date

If you develop any medical or orthopedic problems between now and the test day it is essential that you notify the research staff.

APPENDIX B

SEVEN-DAY PHYSICAL ACTIVITY RECALL QUESTIONNAIRE

7-Day Physical Activity Recall

PAR# 1 2 3 4 5 6 7 Participant____

Interviewer_____________ Today is________ Today's Date________

1. Were you employed in the last seven days? 0. **No** (Skip to Q#4) 1. **Yes**
2. How many days of the last seven did you work? _____ days
3. How many total hours did you work in the last seven days? _____ hours last week
4. What two days do you consider your weekend days?

_________________ and __________________ (mark days below with a squiggle)

WORKSHEET DAYS

	SLEEP	1 ___	2 ___	3 ___	4 ___	5 ___	6 ___	7 ___
MORNING	Moderate							
	Hard							
	Very Hard							
AFTERNOON	Moderate							
	Hard							
	Very Hard							
EVENING	Moderate							
	Hard							
	Very Hard							
Total Min Per Day	Strength: Flexibility:	_____	_____	_____	_____	_____	_____	_____

4a. Compared to your physical activity over the past 3 months, was last weeks physical activity more, less or about the same? **1. More 2. Less 3. About the same**	6. Do you think this was a valid PAR interview? **1. Yes 2. No** **If NO, go to the back and explain**
5. Were there any problems with the PAR interview? **0. No 1. Yes** **If YES, go to the back and explain**	7. Were there any special circumstances concerning this PAR? **0. No 1. Yes, if YES what were they? (circle)** 1. Injury all week 2. Illness all week 3. Illness part week 4. Injury part week 5. Pregnancy 6. Other

Worksheet Key:	**Rounding:** 10-22 min = .25
An asterisk (*) denotes a work –related activity	23-37 min = .50
A squiggly line through a colum (day) denotes	38-52 min = .75
a weekend day	53-1:07 hr/min = 1.0
	1:08-1:22 hr/min = 1.25

5. Explain why there were problems with this PAR interview:

____
____
____

6. If PAR interview was not valid, why was it not valid?

____
____
____

7. Please list below any activities reported by the subject which you do not know how to classify.

____
____
____

8. provide any other comments you may have.

____
____
____
____

APPENDIX C

BORG’S 6-20 RATE OF PERCEIVED EXERTION SCALE

6 No exertion at all

7

Extremely light (7.5)

8

9 Very light

10

11 Light

12

13 Somewhat hard

14

15 Hard (heavy)

16

17 Very hard

18

19 Extremely hard

20 Maximal exertion

9 corresponds to "very light" exercise. For a healthy person, it is like walking slowly at his or her own pace for some minutes

13 on the scale is "somewhat hard" exercise, but it still feels OK to continue.

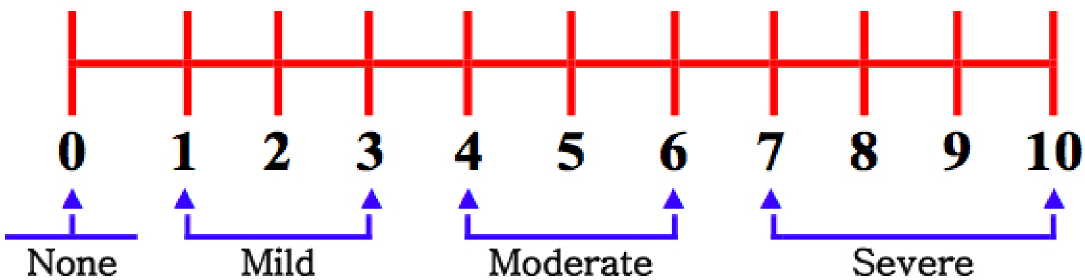
17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired.

19 on the scale is an extremely strenuous exercise level. For most people this is the most strenuous exercise they have ever experienced.

(Borg, G. (*1998*). *Borg's* Perceived Exertion and Pain Scales. Champaign, IL: *Human Kinetics*.)

APPENDIX D

ELEVEN-POINT NUMERICAL RATING SCALE FOR LOWER LEG PAIN


0
1
2
3
4
5
6
7
8
9
10
None
Mild
Moderate
Severe

APPENDIX E

CLASSIC ROLLERSKIING SCRIPT

Person should have filled out the Stanford 7-day recall to best of ability, had baseline intracompartmental pressures and lactate testing performed been fitted/set up with heart rate monitor and completed the NRS for lower leg pain.

“Hi. You are about to begin 20 minutes of classic rollerskiing for Katie Woods’ Master’s Thesis project titled “Changes in anterior and lateral intracompartmental pressures after classic versus skate rollerskiing.” You are expected to maintain 85-90% of your maximum heart rate for at least 75% (or 15 minutes) of the entire test time. This has been calculated for you based on your age.”(ask their name and tell them what their range is). “Your range is____________. You should be participating of a level 15 and 17, which is hard and very hard on the Borg’s RPE scale” (show them the scale). “17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired. Please try to keep your legs moving and resist much double poling during this test. If at any time you feel you are unable to complete the test please pull to the side and stop, a researcher will come to assist you. Make sure to stay in the bike/walking lane during the test but keep an eye out for cars. Keep an eye on your watch and be prepared to stop right at 20 minutes. A researcher will be nearby to assist you into the vehicle for post-exercise intracompartmental testing. It is important that you only ski for 20 minutes. Do you have any questions?”

“Okay you will go on the word begin after I count down from three. Ready? 3...2...1...Begin.”(start timer)

APPENDIX F

SKATE ROLLERSKIING SCRIPT

Person should have filled out the Stanford 7-day recall to best of ability, had baseline intracompartmental pressures and lactate testing performed been fitted/set up with heart rate monitor and completed the NRS for lower leg pain.

“Hi. You are about to begin 20 minutes of skate rollerskiing for Katie Woods’ Master’s Thesis project titled “Changes in anterior and lateral intracompartmental pressures after classic versus skate rollerskiing.” You are expected to maintain 85-90% of your maximum heart rate for at least 75% (or 15 minutes) of the entire test time. This has been calculated for you based on your age.”(ask their name and tell them what their range is). “Your range is____________. You should be participating of a level 15 and 17, which is hard and very hard on the Borg’s RPE scale” (show them the scale). “17 "very hard" is very strenuous. A healthy person can still go on, but he or she really has to push him- or herself. It feels very heavy, and the person is very tired. Please use the V2 method of poling as much as possible during this test to maintain even poling to both sides. If at any time you feel you are unable to complete the test please pull to the side and stop, a researcher will come to assist you. Make sure to stay in the bike/walking lane during the test but keep an eye out for cars. Keep an eye on your watch and be prepared to stop right at 20 minutes. A researcher will be nearby to assist you into the vehicle for post-exercise intracompartmental testing. It is important that you only ski for 20 minutes. Do you have any questions?”

“Okay you will go on the word begin after I count down from three. Ready? 3...2...1...Begin” (start timer).

REFERENCES

Abramowitz, A.J., & Schepsis, A.A. (1994). Chronic exertional compartment syndrome of the leg. *Orthopaedic Review, 23(3),* 219-226.

Allen, M.J., & Barnes, M.R. (1986). Exercise pain in the lower leg. *Journal of Bone and Joint Surgery, 68(B),* 818-823.

Amendola, A., & Rorabeck, C.H. (1985). Chronic exertional compartment syndrome. *Current Therapy in Sports Medicine.* Toronto, BC: Decker.

Amendola, A., & Webster-Bogaert, S. (February,1995). *Diagnostic criteria for the exertional compartment syndrome.* Presented at the Annual Meeting of the American Academy of Orthopedic Surgerons, Orlando, FL, USA.

Anderson, M.K., Parr, G.P., & Hall, S.J. (2006). *Foundations of athletic training: Prevention, assessment, and management.* Philadelphia, PA: Lippincott, Wiliams & Wilkins.

Baltopoulos, P., Papadakou, E., Tsironi, M., Karagounis, P., & Prionas, G. (2008). Pre, distance, and post exercise anterior tibial compartment pressures in long distance runners. *Journal of Sports Science and Medicine, 7(1),* 96-100.

Beckham, S.G., Grana, W.A., Buckley, P., Breazile, J.E., & Claypool, P.L. (1993). A comparison of anterior compartment pressures in competitive runners and cyclists. *The American Journal of Sports Medicine, 21(1),* 36-39.

Black, K.P., & Taylor, D.E. (1993). Current concept in the treatment of common compartment syndrome in athletes. *Sports Medicine*, *15(6),* 406-418.

Blackman, P.G. (2000). A review of chronic exertional compartment syndrome in the lower leg. *Medicine and Science in Sports and Exercise,* 32(3), S4-S10.

Bong, M.R., Polatsch, D.B., Jazrawi, L.M., & Rokito, A.S. (2005) Chronic exertional compartment syndrome: Diagnosis and management. *Hospital for Joint Diseases, 62(3-4),*77-84.

Borg, G. (1998). *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: *Human Kinetics.*

Bourne, R.B., & Rorabeck, C.H. (1989). Compartment syndromes of the lower leg. *Clinical Orthopaedics and Related Research, 240(March),* 97-104.

Cohen, M.M. (2002). How to detect and treat chronic compartment syndrome. *Podiatry Today,15(12),* 40-49.

Cole, L.A., Khanlin, S.A., Sutton J.M., Davies, S., & Rayburn. (2004). Accuracy of home pregnancy tests at the time of missed menses. *American Journal of Obstetrics, 190(1),* 100-105.

Davey, J.R., Rorabeck, C.H., & Fowler, P.J. (1984). The tibialis posterior muscle compartment: An unrecognized cause of exertional compartment syndrome. *The Americal Journal of Sports Medicine, 12(5),* 391-397.

Detmer D.E., Sharpe, K., Sufit, R.L. & Girdley, F.M. (1985). Chronic compartment syndrome: diagnosis, management, and outcomes. *The American Journal of Sports Medicine*, *13(3),* 162-170.

Drake, R.L., Vogl, W., & Mitchell, A.W.M. (2005). *Gray's anatomy for students.* Philadelphia, PA: Elsevier, Inc.

Duggan, R.J., MacGill. A.A., Reeves, C.L., & Goldstein, S.P. (2009). How to diagnose and treat chronic exertional compartment syndrome. *Podiatry Today. 22(6),* 72-74.

Edwards, P., & Myerson, M.S. (1996). Exertional compartment syndrome of the leg: Steps for expedient return to activity. *Physician and Sportsmedicine, 24(4),* 31-46.

Edwards, P.H., Wright, M.L., & Hartman, J.F. (2005). A practical approach for the differential diagnosis of chronic leg pain in the athlete. *The American Journal of Sports Medicine, 33(8),* 1241-1249.

Fortin, F. (2000). *Sports: The complete visual reference*. Buffalo, NY: Firefly Books Inc.

Fraipont, M.J.,& Adamson, G.J. (2003). Chronic exertional compartment syndrome. *Journal of the American Academy of Orthopaedic Surgeons, 11(4),* 268-276.

Freedman, B.J. (1953). Dr. Edward Wilson of the Antarctic. *Proceedings of the Royal Society of Medicine, 47,* 7-13.

Fredericson M., & Wun C. (2003). Differential diagnois of leg pain in the athlete. *Journal of the American Podiatric Medical Association, 93(4),* 321-324.

Gebauer A., Schultz, C.R., & Giangarra, C.E. (2005). Chronic exercise-induced leg pain in an athlete successfully treated with sympathetic block. *The American Journal of Sports Medicine, 33(10),* 1575-1578.

Gerow, G., Matthews, B., Jahn, W., & Gerow, R. (1993). Compartment syndrome and shin splints of the lower leg. *Journal of Manipiulative and Physiological Therapeutics, 16(4),* 245-252.

Gertsch, P., Borgeat, A., & Wälli, T. (1987). New cross-country skiing technique and compartment syndrome. *The American Journal of Sports Medicine, 15(6),* 612-613.

Hislop, M., Tierney, P., Murray, P., O'Brien, M., & Mahony, N. (2003) Chronic exertional compartment syndrome: the controversial "fifth" compartment of the leg. *The American Journal of Sports Medicine, 31(5),* 770-776.

Howard, J.L., Mohtadi, N.G., & Wiley, J.P. (2000). Evaluation of outcomes in patients following surgical treatment of chronic exertional compartment syndrome in the leg. *Clinical Journal of Sport Medicine, 10(3),*176-184.

Jaccard, J. (1998) *Interaction effects in factorials analysis of variance.* Thousand Oaks, CA: Sage.

Lawson, S.K., Reid, D.C., & Wiley, J.P. (1992). Anterior compartment pressures in cross-country skiers: a comparison of classic and skating skis. *The American Journal of Sports Medicine, 20(6),* 750-753.

Jones, D.C., & James, S.L. (1987). Overuse injuries of the lower extremity: Shin splints, iliotibial band friction syndrome, and exertional compartment syndromes. *Clinical Journal of Sport Medicine, 6(2),* 273-290.

Leversedge, F.J., Casey, P.J., Seiler, J.G., & Xerogeanes, J.W. (2002). Endoscopically assisted fasciotomy: Description of technique and in vitro assessment of lower-leg compartment decompression.*The American Journal of Sprots Medicine, 30(2),* 272-278.

Martens, M.A., Backaert, M., Vermaut, G., & Mulier, J.C. (1984). Chronic leg pain in athletes due to a recurrent compartment syndrome. *The American Journal of Sports Medicine, 12(2),* 148-151.

Martens, M.A., & Moeyersoons, J.P. (1990).Acute and effort-related compartment syndromes in sports. *Sports Medicine, 9(1),* 62-68.

Matsen, F.A. (1975). Compartmental syndrome: A unified concept. *Clinical Orthopedics and Related Research, 113,* 8-14.

Mavor, G.E. (1956) The anterior tibial syndrome. *Journal of Bone and Joint Surgery, 38-B(2),* 513-517.

Mazerolle, S.M., McDermott, B., & Silverberg, E. (2008). Bilateral exertional compartment syndrome: A case report. *Athletic Therapy Today, 13(3),* 20-23.

Moed B.R., & Thorderson P.K. (1993). Measurement of intracompartmental pressure: A comparison of the slit catheter, side-ported needle, and simple needle. *Journal of Bone and Joint Surgery, 75(2),* 231-235.

Moeyersoons J.P., & Martens, M. (1992). Chronic compartment syndrome: Diagnosis and management. *Acta Orthopaedica Belgica, 58(1),* 23-27.

Mohler, L.R., Styf, J.R., Pedowitz, R.A., Hargens, A.R., & Gershuni, D.H. (1997). Intramuscular deoxygenation during exercise in patients who have chronic anterior compartment syndrome of the leg. *Journal of Bone and Joint Surgery, 79(6),* 844-849.

Mubarak, S.J. (1989). *Exertional compartment syndrome. Prevention and Treatment of Running Injuries*. Thorofare, NJ: Slack, Inc.

Mubarak, S. J., & Hargens, A.R. *(*1981*) Compartment syndrome* in *Volkmann's contracture*. Philadelphia, PA: WB Saunders.

Padhiar, N. (2009). Chronic compartment syndrome of the leg. *SportEX Medicine, 40(Apr),* 16-22.

Pearse, M.F., Harry, L., & Nanchahal, J. (2002) Acute compartment syndrome of the leg. *British Medical Journal, 325(3764),* 557-558.

Pedowitz, R.A., Hargens, A.R., Mubarak, S.J., & Gershuni, D.H. (1990). Modified criteria for the objective diagnosis of chronic compartment syndrome of the leg. *The American Journal of Sports Medicine, 18(1),* 35-40.

Pedowitz, R.A., & Gershuni, D.H. (1995). Pathophysiology and diagnosis of chronic compartment syndrome. *Operative Techniques in Sports Medicine, 3(4),* 230-236.

Pell, R.F., Khanuja, H.S., & Cooley, G.R. (2004). Leg pain in the running athlete. *The Journal of the American Academy of Orthopaedic Surgeons, 12(6),* 396-404.

Prentice, W.E. (2006). *Arnheim's principles of athletic training. A competency based approach.* Madison, WI: McGraw-Hill.

Puranen, J., & Alavaikko, A. (1981). Intracompartmental pressure increase on exertion in patients with chronic compartment syndrome in the leg. *The Journal of Bone and Joint Surgery, 63(8),* 1304-1309.

Qvarfordt, P., Christenson, J.T., Eklöf, B., Ohlin P., & Saltin B.(1983). Intramuscular pressure, muscle blood flow, and skeletal muscle metabolism in chronic anterior tibial compartment syndrome. *Clinical Orthopaedics and Related Research,179,* 284-290.

Reneman, R.S. (1975). The anterior and lateral compartmental syndrome of the leg due to intensive use of muscles. *Clinical Orthopaedics and Related Research, 113,* 69-80.

Rorabeck, C.H., Bourne, R.B., Fowler, P.J., Finlay, J.B., & Nott, L. (1988). The role of tissue pressure management in diagnosing chronic anterior compartment syndrome. *The American Journal of Sports Medicine, 16,* 143-146.

Rorabeck C.H., Castle G.S.P., Hardie, R., & Logan, J. (1981). Compartmental pressure measurements: An experimental investigation using the slit catheter. *The Journal of Trauma, 21(6),* 446-449.

Rusko, H. (2003). *Cross country skiing.* Malden, MA: Blackwell Science, Inc.

Sallis, J.F., Haskell, P., & Wood, P. (1985). Physical activity assessment methodology in the Five-City Project. *The American Journal of Epidemiology, 121(1),* 91-106.

Starkey, S., & Johnson, G. (2006). *Athletic training and sports medicine.* Boston, MA: Jones and Bartlett.

Stein, D.A., & Sennett, B.J. (2005). One-portal endoscopically assisted fasciotomy for exertional compartment syndrome. *Journal of Arthroscopic and Related Surgery, 21(1),* 108-112.

Styf, J. (1988). Diagnosis of exercise-induced pain in the anterior aspect of the lower leg. *The American Journal of Sports Medicine, 16(2),* 165-169.

Styf, J. (1989) Chronic exercise-induced pain in the anterior aspect of the lower leg. *Sports Medicine, 7(5),* 331-339.

Tanaka, H., Monahan K.D., & Seals D. R. (2001). Age-predicted maximal heart rate revisited. *Journal of the American College of Cardiology, 37(1),* 153-156.

Tanner R.K., Fuller K.L., & Ross M.L. (2010) Evaluation of three portable blood lactate analysers: Lactate pro, lactate scout and lactate plus. *European Journal of Applied Physiology, 109(3),* 551-559.

Touliopoulos, S., & Hershman E.B. (1997). Lower leg pain: Diagnosis and treatment of compartment syndromes and other pain syndromes of the leg. *Sports Medicine, 27(3)*, 193-204.

Turnipseed, W., Detmer, D., &Girdley, F. (1989). Chronic compartment syndrome: An unusual cause for claudication. *Annals of Surgery, 210(4)*, 557-563.

Verleisdonk, E.J.M.M., Schmitz, R.F., & van der Werken, C. (2004). Long-term results of fasciotomy of the anterior compartment in patients with exercise-induced pain in the lower leg. *International Journal of Sports Medicine, 25(3)*, 224-229.

Volkmann, R. (1881). Die ischamischen muskallahmangen und kontrakturen. *Centralblatt fur Chirugerie, 51*, 799-803.

Wilder, R.P., & Sethi, S. (2004). Overuse injuries: Tendinopathies, stress fractures, compartment syndrome, and shin splints. *Clinical Journal of Sports Medicine, 23(1)*, 55-81.

Woods, K.M, Nakagama, N.K., Yochem, E. M., & Hicks-Little, C. A. (2010). Anterior compartment syndrome in a collegiate male Nordic skier: A case report. Poster Presentation. *NATA Annual Convention, Philadelphia, PA.*